CHAPTER SIXTEEN

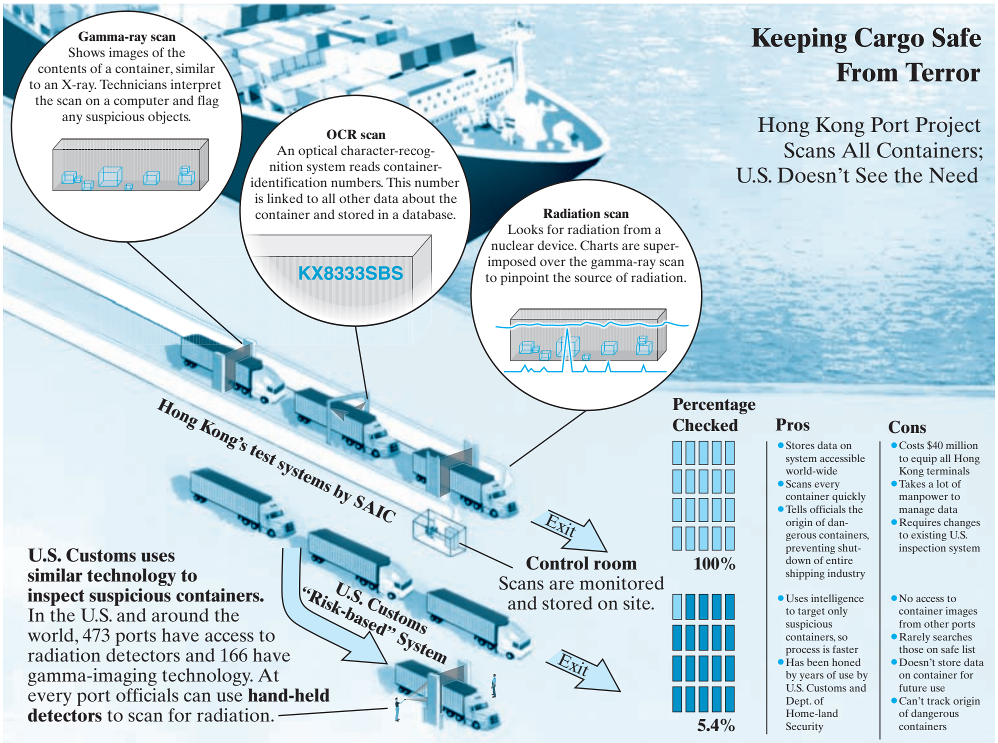
Economic Analysis in the Service Sector

***Keeping Cargo Safe from Terror*[1]** How do you keep a terrorist from smuggling a radiation-filled "dirty bomb" or other weapon in one of the seven-million-plus shipping containers that arrive at U.S. ports each year? Until now, U.S. Customs and Border Protection has sought to secure global shipping by relying on intelligence and scrutinizing suspicious cargo manifests—such as an unrefrigerated container full of "frozen fish"—to identify potentially dangerous shipments. Currently, less than 6% of the containers headed for American ports are deemed "high risk" by the U.S. Department of Homeland Security and pulled aside for examination by Custom inspectors.

Port officials in Hong Kong are testing a strategy that electronically scrutinizes every container full of sneakers, toys, gadgets, or other contents. Trucks haul each container passing through the port through two of the giant scanners. One checks for nuclear radiation, while the other uses gamma rays to seek out any dense, suspicious object made of steel or lead inside the containers that could shield a bomb from the nuclear detector. Proponents contend it better secures the global shipping system—without unacceptably slowing the flow of commerce. The Hong Kong project would cost shippers an additional $6.50 a container if its costs were passed on to them. That is a fraction of what it costs to transport a container: about $1,900 to send a 20-foot container from Hong Kong to Los Angeles.

Now, U.S. Customs and Border protection is examining the various options for inspecting the incoming cargo, including a 100% inspection. Clearly, one of the main issues to address is how to minimize the obvious congestion that would result at the ports and borders. This will

[1] "Keeping Cargo Safe from Terror," by Alex Ortolani and Robert Block, *The Wall Street Journal*, Friday, July 29, 2005, Section B1.



undoubtedly add a huge burden to the U.S. economy, not to mention the cost of installing the scanners all over the border entry points.

Up to this point, we have focused our analysis on the economic issues related to the manufacturing sector of the U.S. economy. The main reason for doing this was that many engineers will be working in that sector. However, an increasing number of engineers are now seeking their careers in the service sector, such as health care, financial institutions, transportation and logistics, and government. In this chapter, we will present some unique features that must be considered in evaluating investment projects in the service sector.

CHAPTER LEARNING OBJECTIVES

After completing this chapter, you should understand the following concepts:

- How to price service.
- How to evaluate investment projects in the health care industry.
- How to conduct cost benefit analysis and cost effectiveness analysis.

16.1 What Is the Service Sector?[2]

The service sector of the U.S. economy dominates both gross domestic product (GDP) and employment. It is also the fastest-growing part of the economy and the one offering the most fertile opportunities to engineers to improve their productivity. For example, service activities now approach 80% of U.S. employment, far outstripping sectors such as manufacturing (14%) and agriculture (2%), as shown in Figure 16.1.

The mere scale of the service sector makes it a critical element of the U.S. economy, employing, as it does, many millions of workers producing trillions of dollars in economic value. The service sector has expanded far beyond the traditional consumer or institutional service industries and currently includes distributive services, such as transportation, communications, and utilities; the rapidly expanding producer services, such as finance, insurance, real estate, and advertising; wholesale and retail trade and sales; the nonprofit sector, including health, philanthropy, and education; and government. The use of technology in the service sector promotes deskilling (i.e., automation). However, secure and reliable U.S. services provide much of the key infrastructure on which the whole nation, and indeed much of the world's commerce, depends. Tremendous new challenges have arisen as changes in processes and operations are developed to better assure the safety and reliability of critical services. These changes all lead to significant investment in infrastructures requiring detailed economic analysis.

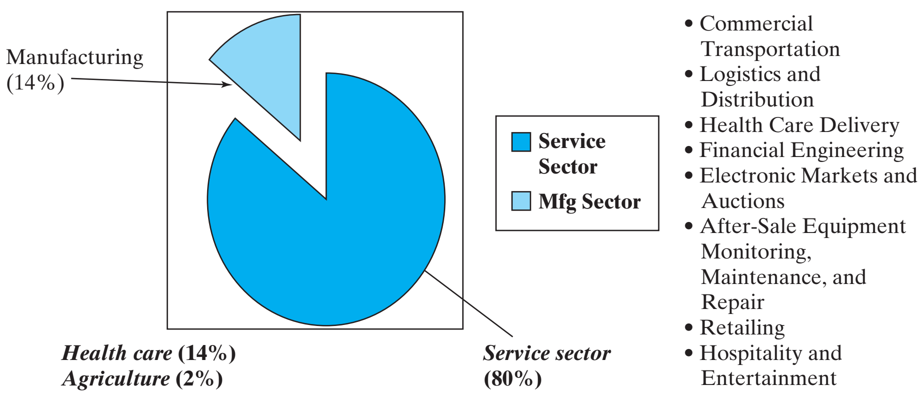


Figure 16.1 Contribution of the service sector to the U.S. gross domestic product (GDP).

[2] This section is taken from the National Science Foundation program "Exploratory Research on Engineering the Service Sector (ESS)," NSF 02-029.

16.1.1 Characteristics of the Service Sector

What makes the evaluation of a service sector project unique compared with one from the manufacturing sector? Some of the unique features are summarized as follows:

- Services are generally intangible. They have sometimes been defined as "anything of economic value that cannot be held or touched."
- It is usually impossible to build inventories of services. Either the demand for the service must be backlogged, or enough resources need to be provided to meet an acceptable fraction of the demand as it arises.
- Services are more dynamic and responsive to demand than are manufactured products. This means that variability and risk are more central issues in service industries. Indeed, the management of financial risk is an important service in itself.
- Many services (examples are medical treatment and equipment repair) require a diagnostic step to design the service as part of its delivery. Coproduction (i.e., active collaboration between the server and the customer) is also required in many settings.
- Service products are usually less standardized and less subject to design specifications than manufactured goods are, because the outputs are tailored to customer needs as they are delivered. This also makes it harder to distinguish service product design from product manufacture and delivery.
- The dimensions of service quality are more subtle and subjective than those of physical products. Not only are the parameters of services more difficult to express, but customers' perceptions play a much greater role in deciding what is satisfactory or valuable.
- Most service operations are more labor intensive than the production of goods.
- Compared with goods industries, the service economy has a much greater fraction of its operations performed by governments and institutions.
- Information technology is central to service industries. Often, it is the only significant means of multiplying human output.

Certainly, our objective is not to address all aspects of the service sector, but only some of the common economic analysis issues confronted by its engineers.

16.1.2 How to Price Service

Improving service can be many different things. For example, for a delivery business such as United Parcel Service (UPS) or FedEx, anything that reduces the total time taken from pickup to delivery is considered an improvement of service. For an airline, on-time departures and arrivals, a reduction in the number of mishandled pieces of checked-in baggage, and a speedy check-in at the gate could all be considered important service parameters, because they make airline passengers happy, which in turn will translate into more business volume. Accordingly, one of the critical questions related to improvement in service is "What do service providers gain by improving their own service to suppliers and customers?" If we can quantify improvements in service in terms of dollars, the economic analysis is rather straightforward: If the net increase in revenue due to improvements in service exceeds the investment required, the project can be justified. For this type of decision problem, we can simply use any of the measures of investment worth discussed in Chapter 5 through Chapter 7.

Improving service is one thing and putting a price on services is another thing. This is far more difficult than pricing products, because the benefits of services are less tangible and service companies often lack well-documented standard unit-production costs to go by. When

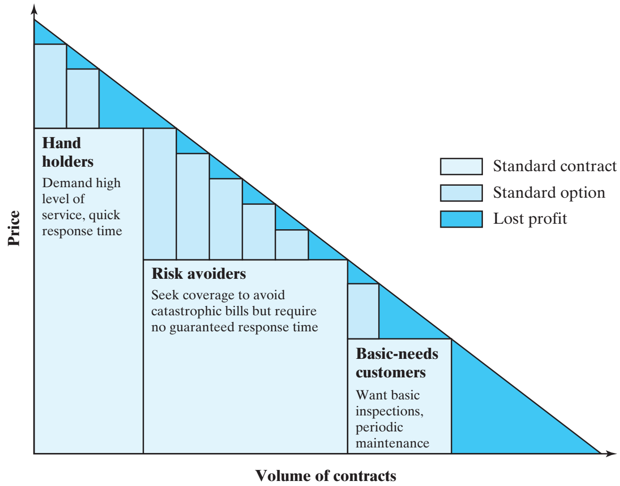


Figure 16.2 How to capture lost profits. By segmenting customers into three categories with appropriate service options, companies can capture much of the lost profit. Options may include guaranteed response time, remote equipment monitoring, or extended warranty.

a company designs an after-service contract to go with equipment sales, customers may be segmented according to their service needs rather than their size, industry, or type of equipment. Companies then develop the pricing, contracting, and monitoring capabilities to support the cost-effective delivery of the service.[3] For example, when customers are segmented according to the service level they need, they tend to fall into one of at least three common categories. The "basic-needs customers" want a standard level of service with basic inspections and periodic maintenance. The "risk avoiders" are looking for coverage to avoid big bills but care less about other elements, such as response times. And the "hand holders" need high levels of service, often with quick and reliable response times, and are willing to pay for the privilege. Therefore, to maximize return, companies need to capture tremendous value from their service businesses by taking a more careful, fact-based approach to designing and pricing services (Figure 16.2).

The types of service problems that we are interested in this chapter, however, are (1) those encountered by nonprofit organizations such as hospitals or public policy makers on health care and (2) those involving economic decisions by the public sector. In the next section, we will review some of the common decision tools adopted by the health-care service industry. The economic issues in the public sector will be discussed in Section 16.3.

16.2 Economic Analysis in Health-Care Service

The health-care service industry alone constitutes 14–15% of GDP when all its dimensions are included. Clearly, health care is one of the largest, most research-intensive service industries in the United States. Accordingly, its medical knowledge base is

[3] *Source*: Russell G. Bundschuh and Theodore M. Dezvane, "How to Make After-Sales Services Pay Off," *The McKinsey Quarterly*, 2003, no. 4, pp. 3–13.

expanding at a staggering pace, and many Americans enjoy unparalleled advancements in medical science and technology. At the same time, the nation's health-care system consistently fails to deliver high-quality care: Variation in both access to and delivery of care is considerable, errors are widespread, costs are spiraling, and few resources are devoted to optimizing system operations and improving the delivery of care.

16.2.1 Economic Evaluation Tools

Economic evaluation can be used to inform decision making and can provide information to assist in answering the following questions:

- What services do we provide (or improve), when, and at what level?
- How do we provide such services?
- Where do we provide the services?
- What are the costs associated with providing or improving the services?

The following three methods of economic evaluation are related to health service:

- **Cost-effectiveness analysis.** This technique is used in health economics to compare the financial costs of therapies whose outcomes can be measured purely in terms of their health effect (e.g., years of life saved or ulcers healed). Cost-effectiveness analysis (CEA) is the most commonly applied form of economic analysis in health economics. However, it does not allow comparisons to be made between courses of action that have different health effects.
- **Cost-utility analysis.** This technique is similar to CEA in that there is a defined outcome and the cost to achieve that outcome is measured in money. The outcome is measured in terms of survival and quality of life (for example, quality-adjusted life years, or QALYs). CEA can indicate which one of a number of alternative interventions represents the best value for money, but it is not as useful when comparisons need to be made across different areas of health care, since the outcome measures used may be very different. As long as the outcome measure is life years saved or gained, a comparison can still be made, but even in such situations CEA remains insensitive to the *quality*-of-life dimension. In order to know which areas of health care are likely to provide the greatest benefit in improving health status, a cost-utility analysis[4] needs to be undertaken using a common currency for measuring the outcomes across health-care areas.
- **Cost–benefit analysis.** If information is needed as to which interventions will result in overall resource savings, a cost–benefit analysis (CBA) has to be performed, although, like a cost-utility analysis, a cost-benefit analysis has its own drawbacks. In CBA, the benefit is measured as the associated economic benefit of an intervention; hence, both costs and benefits are expressed in money, and the CBA may ignore many intangible, but very important, benefits that are difficult to measure in monetary terms (e.g., relief of pain and anxiety). Even though the virtue of this analysis is that it enables comparisons to be made between schemes in very different areas of health care, the approach is not widely accepted for use in health economics.

Cost–benefit analysis is the process of weighing the total expected cost vs. the total expected benefits of one or more actions in order to choose the best or most profitable option.

[4] We will not discuss any technical details of the cost-utility approach in this chapter, but they can be found in a variety of health economics texts.

16.2.2 Cost-Effectiveness Analysis

In cost-effectiveness analysis (CEA), outcomes are reported in a single unit of measurement. CEA compares the costs and health effects of an intervention to assess whether it is worth doing from an economic perspective. First of all, CEA is a specific type of economic analysis in which all costs are related to a single, common effect. Decision makers can use it to compare different resource allocation options in like terms. A general misconception is that CEA is merely a means of finding the least expensive alternative or getting the "most bang for the buck." In reality, CEA is a comparison tool; it will not always indicate a clear choice, but it will evaluate options quantitatively and objectively on the basis of a defined model. CEA was designed to evaluate health-care interventions, but the methodology can be used for non-health-economic applications as well. CEA can compare any resource allocation with measurable outcomes.

What Constitutes a Cost?

In CEA, it is common to distinguish between the direct costs and the indirect costs associated with an intervention. Some interventions may also result in intangibles, which are difficult to quantify, but should be included in the cost profile. Examples of these different kinds of costs are as follows:

- **Direct cost.** Drugs, medical staff time, medical equipment, transport, and out-of-pocket expenses by the patients.
- **Indirect costs.** Loss of productive time by the patients during the intervention.
- **Intangibles.** Pain and suffering, and adverse effects from the intervention.

It is essential to specify which costs are included in a CEA and which are not, to ensure that the findings are not subject to misinterpretation.

Cost-Effectiveness Ratio

The cost-effectiveness ratio is simply the sum of all costs, divided by the sum of all health effects:

$$\text{Cost-effectiveness ratio} = \frac{\sum(\text{all costs})}{\sum(\text{all measured health effects})} \tag{16.1}$$

The benefits are not measured in terms of just dollars, but in a ratio that incorporates both health outcomes and dollars.

Cost-effectiveness ratios should be related to the size of relevant budgets to determine the most cost-effective strategies. CEAs compare several program strategies and rank them by cost-effectiveness ratios. An analysis of two screening interventions might show you that one costs \$10,000 per life year gained while the other costs \$40,000 per life year gained. The first intervention requires monthly screening and the second requires biannual screening. Realizing that compliance is a greater problem with monthly screening, the decision maker would implement the most appropriate coverage strategy for the population in question. Sometimes, the analysis compares an option against a baseline option, such as "Do nothing" or "Give usual care." The last two are valid strategic options.

Discounting

There is often a significant time lag between the investment of health service resources and the arrival of the associated health gain. In general, we prefer to receive benefits now and pay costs in the future. In order to reflect this preference in economic evaluation, costs are discounted.

16.2.3 How to Use a CEA[5]

When we use a CEA, we need to distinguish between those interventions which are completely independent and those which are dependent. Two (or more) interventions are said to be **independent** if the costs and effects of one neither affect nor are affected by the costs and effects of the other. Two (or more) interventions are dependent if the implementation of one results in changes to the costs and effects of the other. The analysis proceeds as follows:

- **Independent interventions.** Using CEA with independent intervention programs requires that cost-effectiveness ratios be calculated for each program and placed in rank order. For example, in Table 16.1, there are three interventions for different patient groups, and each intervention has as an alternative "doing nothing." According to CEA, Program C should be given priority over Program A, since it has a lower cost-effectiveness ratio (CER), but in order to decide which program to implement, the extent of the resources available must be considered. (See Table 16.2.) Clearly, the choice of independent intervention is a function of the budget that is available to implement. For example, with $200,000, we will go with Program C, and the remaining $50,000 will be available for funding (up to 50%) of Program A.
- **Mutually exclusive interventions.** In reality, the likelihood is that choices will have to be made between different treatment regiments for the same condition and between

TABLE 16.1 **Cost-Effectiveness of Three Independent Intervention Programs**

Program	Cost ($)	Health Effect (Life Years Gained)	Cost-Effectiveness Ratio
A	100,000	1,200	83.33
B	120,000	1,350	88.89
C	150,000	1,850	81.08

TABLE 16.2 **Choices of Program as a Function of Budget**

Budget Available ($)	Programs to Be Implemented
Less than $150,000	As much of C as budget allows
$150,000	100% of C
$150,000–$250,000	C and as much of A as budget allows
$250,000	C and A
$250,000–$370,000	C and A, and as much of B as budget allows
$370,000	All three programs, A, B, C

[5] This section is based on the article "What Is Cost-effectiveness?" by Ceri Phillips and Guy Thompson, vol. 1, no. 3, Hayward Medical Communications, Copyright © 2001; on the Internet at www.evidence-based-medicine.co.uk.

TABLE 16.3 Mutually Exclusive Intervention Programs

Program	Cost	Effects (LifeYears Gained)	Cost-Effectiveness (LifeYears Gained)	Incremental Cost-Effectiveness Ratio
P1	\$125,000	1,300	96.15	96.15
P2	\$100,000	1,500	66.67	−125
P3	\$160,000	2,000	80.00	120
P4	\$140,000	2,200	63.63	−100
P5	\$170,000	2,600	65.38	75

different dosages or treatments versus prophylaxis (i.e., mutually exclusive interventions). In this case, incremental cost-effectiveness ratios (ΔCERs) should be used:

$$\Delta\text{CER}_{2-1} = \frac{\text{Cost of P2} - \text{Cost of P1}}{\text{Effects of P2} - \text{Effects of P1}}$$

The alternative interventions are ranked according to their effectiveness—on the basis of securing the maximum effect rather than considering cost—and CERs are calculated as shown in Table 16.3. The analysis proceeds as follows:

- If money is no object, P5 is clearly the best alternative, as the number of life years gained is most significant.
- The least effective intervention (P1) has the same average CER as its incremental cost-effectiveness ratio (ICER), because it is compared with the alternative of "doing nothing":

$$\Delta\text{CER}_{1-0} = \frac{125{,}000 - 0}{1{,}300 - 0} = 96.15.$$

- A comparison between P1 and P2 yields

$$\Delta\text{CER}_{2-1} = \frac{\text{Cost of P2} - \text{Cost of P1}}{\text{Effect of P2} - \text{Effect of P1}} = \frac{100{,}000 - 125{,}000}{1{,}500 - 1{,}300} = -125 < 96.15.$$

The negative ICER for P2 means that adopting P2 rather than P1 results in an improvement in life years gained and a reduction in costs. It also indicates that P2 dominates P1. Hence, we can eliminate P1 at this stage of the analysis.

- A comparison between P2 and P3 yields

$$\Delta\text{CER}_{3-2} = \frac{160{,}000 - 100{,}000}{2{,}000 - 1{,}500} = 120 > 66.67.$$

The ICER for P3 works out to be 120, which means that it costs $120 to generate each additional life year gained compared with P2. Thus, there is no clear dominance between P2 and P3.

- A comparison between P4 and P3 yields

$$\Delta CER_{4-3} = \frac{140{,}000 - 160{,}000}{2{,}200 - 2{,}000}$$
$$= -100 < 80.$$

P4 is more effective than P3 as the incremental cost-effectiveness ratio becomes negative. Also, P4 dominates P3, so we can eliminate P3 from the analysis. Having excluded P1 and P3, we now recalculate for P2, P4, and P5, as shown in Table 16.4.

- A comparison between P2 and P4 yields

$$\Delta CER_{4-2} = \frac{140{,}000 - 100{,}000}{2{,}200 - 1{,}500}$$
$$= \$57.14 < 66.67.$$

Thus, P2 is dominated by P4, since the latter is more effective and costs less to produce an additional unit of effect ($57.14 compared with $66.67). The dominated alternative is then excluded and the ICERs are recalculated again (Table 16.5).

TABLE 16.4 **Remaining Mutually Exclusive Alternatives after Eliminating More Costly and Less Effective Programs**

Program	Cost	Effects (Life Years Gained)	Cost-Effectiveness (Life Years Gained)	Incremental Cost-Effectiveness Ratio
P2	$100,000	1,500	66.67	66.67
P4	$140,000	2,200	63.63	57.14
P5	$170,000	2,600	65.38	75.00

TABLE 16.5 **Remaining Mutually Exclusive Alternatives after Eliminating All Dominated Programs**

Program	Cost	Effects (Life Years Gained)	Cost-Effectiveness (Life Years Gained)	Incremental Cost-Effectiveness Ratio
P4	$140,000	2,200	63.63	63.63
P5	$170,000	2,600	65.38	75.00

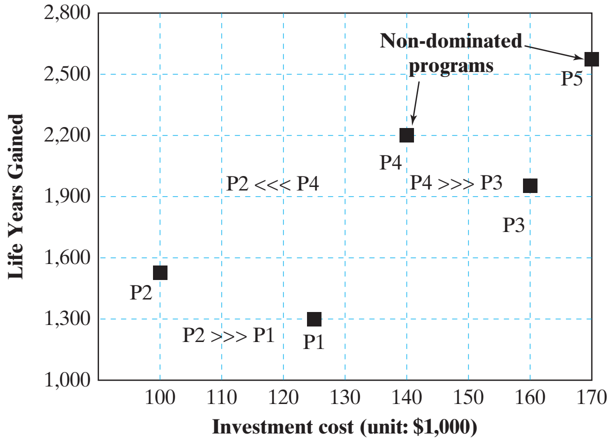


Figure 16.3 Cost-effectiveness diagram—Life years gained.

- Finally, a comparison between P4 and P5 yields

$$\Delta\text{CER}_{5-4} = \frac{170{,}000 - 140{,}000}{2{,}600 - 2{,}200}$$
$$= 75 > 63.63.$$

No clear dominance exists between P4 and P5. As shown in Figure 16.3, these two programs are therefore the ones that deserve funding consideration. In deciding between them, the size of the available budget must be brought to bear on the matter. If the available budget is \$140,000, all patients should receive intervention P4, whereas if the available budget is \$170,000, all patients should receive the more effective P5. However, if the budget is, say, \$150,000, then, since the cost difference between P4 and P5 is \$30,000 and the budget surplus is \$10,000, it is possible to switch one-third of the patients to P5 and still remain within budget.

16.3 Economic Analysis in the Public Sector

In earlier chapters, we have focused attention on investment decisions in the private sector; the primary objective of these investments was to increase the wealth of corporations. In the public sector, federal, state, and local governments spend hundreds of billions of dollars annually on a wide variety of public activities, such as the port project described in the chapter opener. In addition, governments at all levels regulate the behavior of individuals and businesses by influencing the use of enormous quantities of productive resources. How can public decision makers determine whether their decisions, which affect the use of these productive resources, are, in fact, in the best public interest?

Many civil engineers work on public-works areas such as highway construction, airport construction, and water projects. In the port expansion scenario presented at the beginning of the chapter, each option requires a different level of investment and produces a different degree of benefits. One of the most important aspects of airport expansion is to quantify the cost of airport delays in dollar terms. In other words, planners ask, "What is the economic benefit of reducing airport delays?" From the airline's point of view, taxiing and arrival delays mean added fuel costs. For the airport, delays mean lost revenues in landing and departure fees. From the public's point of view, delays mean lost earnings, as people then have to spend more time on transportation. Comparing the investment costs with the potential benefits, an approach known as benefit–cost analysis, is an important feature of economic analysis.

16.3.1 What Is Benefit–Cost Analysis?

Benefit–cost analysis is a decision-making tool that is used to systematically develop useful information about the desirable and undesirable effects of public projects. In a sense, we may view benefit–cost analysis in the public sector as profitability analysis in the private sector. In other words, benefit–cost analysis attempts to determine whether the social benefits of a proposed public activity outweigh the social costs. Usually, public investment decisions involve a great deal of expenditure, and their benefits are expected to occur over an extended period of time. Examples of benefit–cost analysis include studies of (1) public transportation systems, (2) environmental regulations on noise and pollution, (3) public-safety programs, (4) education and training programs, (5) public-health programs, (6) flood control, (7) water resource development, and (8) national defense programs.

Benefit–cost analysis: A technique designed to determine the feasibility of a project or plan by quantifying its costs and benefits.

The three typical aims of benefit–cost analyses are (1) to maximize the benefits for any given set of costs (or budgets), (2) to maximize the net benefits when both benefits and costs vary, and (3) to minimize costs to achieve any given level of benefits (often called "cost-effectiveness" analysis). Three types of decision problems, each having to do with one of these aims, will be considered in this chapter.

16.3.2 Framework of Benefit–Cost Analysis

To evaluate public projects designed to accomplish widely differing tasks, we need to measure the benefits or costs in the same units in all projects so that we have a common perspective by which to judge the different projects. In practice, this means expressing both benefits and costs in monetary units, a process that often must be performed without accurate data. In performing benefit–cost analysis, we define **users** as the public and **sponsors** as the government.

The general framework for benefit–cost analysis can be summarized as follows:

1. Identify all users' benefits expected to arise from the project.
2. Quantify these benefits in dollar terms as much as possible, so that different benefits may be compared against one another and against the costs of attaining them.
3. Identify sponsors' costs.
4. Quantify these costs in dollar terms as much as possible, to allow comparisons.
5. Determine the equivalent benefits and costs during the base period; use an interest rate appropriate for the project.
6. Accept the project if the equivalent users' benefits exceed the equivalent sponsor's costs.

We can use benefit–cost analysis to choose among such alternatives as allocating funds for the construction of a mass-transit system, a dam with irrigation, highways, or an air-traffic control system. If the projects are on the same scale with respect to cost, it is merely a question of choosing the project for which the benefits exceed the costs by the greatest amount. The steps just outlined are for a single (or independent) project evaluation. As in the case of the internal-rate-of-return criterion, in comparing mutually exclusive alternatives, an incremental benefit–cost ratio must be used. Section 16.3.3 illustrates this important issue in detail.

16.3.3 Valuation of Benefits and Costs

In the abstract, the framework we just developed for benefit–cost analysis is no different from the one we have used throughout this text to evaluate private investment projects. The complications, as we shall discover in practice, arise in trying to identify and assign values to all the benefits and costs of a public project.

Users' Benefits

To begin a benefit–cost analysis, we identify all project **benefits** (favorable outcomes) and **disbenefits** (unfavorable outcomes) to the user. We should also consider the indirect consequences resulting from the project—the so-called **secondary effects**. For example, the construction of a new highway will create new businesses such as gas stations, restaurants, and motels (benefits), but it will divert some traffic from the old road, and as a consequence, some businesses would be lost (disbenefits). Once the benefits and disbenefits are quantified, we define the users' benefits as follows:

$$\text{Users' benefits } (B) = \text{Benefits} - \text{Disbenefits}.$$

In identifying user's benefits, we should classify each one as a **primary benefit**—a benefit that is directly attributable to the project—or a **secondary benefit**—a benefit that is indirectly attributable to the project. As an example, at one time the U.S. government was considering building a superconductor research laboratory in Texas. If the project ever materializes, it could bring many scientists and engineers, along with other supporting population, to the region. Primary national benefits might include the long-term benefits that could accrue as a result of various applications of the research to U.S. businesses. Primary regional benefits might include economic benefits created by the research laboratory activities, which would generate many new supporting businesses. Secondary benefits might include the creation of new economic wealth as a consequence of a possible increase in international trade and an increase in the incomes of various regional producers attributable to a growing population.

The reason for making this distinction is that it may make our analysis more efficient: If primary benefits alone are sufficient to justify project costs, we can save time and effort by *not* quantifying the secondary benefits.

Sponsor's Costs

We determine the cost to the sponsor by identifying and classifying the expenditures required and any savings (or revenues) to be realized. The sponsor's costs should include both capital investment and annual operating costs. Any sales of products or services that take place upon completion of the project will generate some revenues—for example, toll revenues on highways. These revenues reduce the sponsor's costs. Therefore, we calculate the sponsor's costs by combining these cost elements:

$$\text{Sponsor's cost} = \text{Capital cost} + \text{Operating and maintenance costs} - \text{Revenues}.$$

Social Discount Rate

As we learned in Chapter 15, the selection of an appropriate MARR for evaluating an investment project is a critical issue in the private sector. In public-project analyses, we also need to select an interest rate, called the **social discount rate**, to determine equivalent benefits as well as the equivalent costs. The selection of a social discount rate in public project evaluation is as critical as the selection of a MARR in the private sector.

Ever since present-value calculations were initiated to evaluate public water resources and related land-use projects in the 1930s, a tendency to use relatively low rates of discount compared with those existing in markets for private assets has persisted. During the 1950s and into the 1960s, the rate for water resource projects was 2.63%, which, for much of that period, was even below the yield on long-term government securities. The persistent use of a lower interest rate for water resource projects is a political issue. In recent years, with the growing interest in performance budgeting and systems analysis in the 1960s, the tendency on the part of government agencies has been to examine the appropriateness of the discount rate in the public sector in relation to the efficient allocation of resources in the economy as a whole. Two views of the basis for determining the social discount rate prevail:

1. **Projects without private counterparts.** *The social discount rate should reflect only the prevailing government borrowing rate*. Projects such as dams designed purely for flood control, access roads for noncommercial uses, and reservoirs for community water supply may not have corresponding private counterparts. In those areas of government activity where benefit–cost analysis has been employed in evaluation, the rate of discount traditionally used has been the cost of government borrowing. In fact, water resource project evaluations follow this view exclusively.
2. **Projects with private counterparts.** *The social discount rate should represent the rate that could have been earned had the funds not been removed from the private sector*. For public projects that are financed by borrowing at the expense of private investment, we may focus on the opportunity cost of capital in alternative investments in the private sector to determine the social discount rate. In the case of public capital projects, similar to some in the private sector that produce a commodity or a service (such as electric power) to be sold on the market, the rate of discount employed would be the average cost of capital as discussed in Chapter 15. The reasons for using the private rate of return as the opportunity cost of capital in projects similar to those in the private sector are (1) to prevent the public sector from transferring capital from higher yielding to lower yielding investments and (2) to force public-project evaluators to employ market standards in justifying projects.

The Office of Management and Budget (OMB) holds the second view. Since 1972, OMB has required that a social discount rate of 10% be used to evaluate federal public projects. (Exceptions include water resource projects.)

16.3.4 Quantifying Benefits and Costs

Now that we have defined the general framework for benefit–cost analysis and discussed the appropriate discount rate, we will illustrate the process of quantifying the benefits and costs associated with a public project. Our context is a motor-vehicle inspection program initiated by the state of New Jersey.[6]

Many states in the United States employ inspection systems for motor vehicles. Critics often claim that these programs lack efficacy and have a poor benefit-to-cost ratio in terms of reducing fatalities, injuries, accidents, and pollution.

Elements of Benefits and Costs

The state of New Jersey identified the primary and secondary benefits of its new inspection program as follows:

- **Users' Benefits**

  Primary benefits. Deaths and injuries related to motor-vehicle accidents impose financial costs on individuals and society. Preventing such costs through the inspection program has the following primary benefits:

  1. Retention of contributions to society that might be lost due to an individual's death.
  2. Retention of productivity that might be lost while an individual recuperates from an accident.
  3. Savings of medical, legal, and insurance services.
  4. Savings on property replacement or repair costs.

  Secondary benefits. Some secondary benefits are not measurable (e.g., the avoidance of pain and suffering); others can be quantified. Both types of benefits should be considered. A list of secondary benefits is as follows:

  1. Savings of income of families and friends of accident victims who might otherwise be tending to the victims.
  2. Avoidance of air and noise pollution and savings on fuel costs.
  3. Savings on enforcement and administrative costs related to the investigation of accidents.
  4. Avoidance of pain and suffering.

- **Users' Disbenefits**

  1. Cost of spending time to have a vehicle inspected (including travel time), as opposed to devoting that time to an alternative endeavor (opportunity cost).
  2. Cost of inspection fees.
  3. Cost of repairs that would not have been made if the inspection had not been performed.

[6] Based on Loeb, P. D. and Gilad, B. "The Efficacy and Cost Effectiveness of Vehicle Inspection," Journal of Transport Economics and Policy, May 1984: 145--164. The original cost data, which were given in 1981 dollars, were converted to the equivalent cost data in 2000 by using the prevailing consumer price indices during the period.

4. Value of time expended in repairing the vehicle (including travel time).
5. Cost in time and direct payment for reinspection.

- **Sponsor's Costs**

1. Capital investments in inspection facilities.
2. Operating and maintenance costs associated with inspection facilities. (These include all direct and indirect labor, personnel, and administrative costs.)

- **Sponsor's Revenues or Savings**

1. Inspection fee.

Valuation of Benefits and Costs

The aim of benefit–cost analysis is to maximize the equivalent value of all benefits minus that of all costs (expressed either in present values or in annual values). This objective is in line with promoting the economic welfare of citizens. In general, the benefits of public projects are difficult to measure, whereas the costs are more easily determined. For simplicity, we will attempt only to quantify the primary users' benefits and sponsor's costs on an annual basis.

- **Calculation of Primary Users' Benefits**

1. **Benefits due to the reduction of deaths.** The equivalent value of the average income stream lost by victims of fatal accidents[7] was estimated at \$571,106 per victim, in 2000 dollars. The state estimated that the inspection program would reduce the number of annual fatal accidents by 304, resulting in a potential savings of

$$(304)(\$571{,}106) = \$173{,}616{,}200.$$

2. **Benefits due to the reduction of damage to property.** The average cost of damage to property per accident was estimated at \$1,845. This figure includes the cost of repairs for damages to the vehicle, the cost of insurance, the cost of legal and court administration, the cost of police accident investigation, and the cost of traffic delay due to accidents. The state estimated that accidents would be reduced by 37,910 per year and that about 63% of all accidents would result in damage to property only. Therefore, the estimated annual value of benefits due to a reduction in property damage was estimated at

$$\$1{,}845(37{,}910)(0.63) = \$44{,}073{,}286.$$

The overall annual primary benefits are estimated as the following sum:

Value of reduction in fatalities	\$173,616,200
Value of reduction in property damage	44,073,286
Total	\$217,689,486

[7] These estimates were based on the total average income that these victims could have generated had they lived. The average value on human life was calculated by considering several factors, such as age, sex, and income group.

- **Calculation of Primary Users' Disbenefits**

1. **Opportunity cost associated with time spent bringing vehicles in for inspection.** This cost is estimated as

$$\begin{aligned} C_1 &= (\text{Number of cars inspected}) \\ &\quad \times (\text{Average duration involved in travel}) \\ &\quad \times (\text{Average wage rate}). \end{aligned}$$

With an estimated average duration of 1.02 travel-time hours per car, an average wage rate of \$14.02 per hour, and 5,136,224 inspected cars per year, we obtain

$$\begin{aligned} C_1 &= 5{,}136{,}224(1.02)(\$14.02) \\ &= \$73{,}450{,}058. \end{aligned}$$

2. **Cost of inspection fee.** This cost may be calculated as

$$C_2 = (\text{Inspection fee}) \times (\text{number of cars inspected}).$$

Assuming that an inspection fee of \$5 is to be paid for each car, the total annual inspection cost is estimated as

$$\begin{aligned} C_2 &= (\$5)(5{,}136{,}224) \\ &= \$25{,}681{,}120. \end{aligned}$$

3. **Opportunity cost associated with time spent waiting during the inspection process.** This cost may be calculated by the formula

$$\begin{aligned} C_3 &= (\text{Average waiting time in hours}) \\ &\quad \times (\text{Average wage rate per hour}) \\ &\quad \times (\text{Number of cars inspected}). \end{aligned}$$

With an average waiting time of 9 minutes (or 0.15 hours),

$$C_3 = 0.15(\$14.02)(5{,}136{,}224) = \$10{,}801{,}479.$$

4. **Vehicle usage costs for the inspection process.** These costs are estimated as

$$\begin{aligned} C_4 &= (\text{Number of inspected cars}) \\ &\quad \times (\text{Vehicle operating cost per mile}) \\ &\quad \times (\text{Average round-trip miles to inspection station}). \end{aligned}$$

Assuming a \$0.35 operating cost per mile and 20 round-trip miles, we obtain

$$C_4 = 5{,}136{,}224(\$0.35)(20) = \$35{,}953{,}568.$$

The overall primary annual disbenefits are estimated as follows:

Item	Amount
C_1	\$73,450,058
C_2	25,681,120
C_3	10,801,479
C_4	35,453,568
Total disbenefits	\$145,886,225, or \$28.40 per vehicle

- **Calculation of Primary Sponsor's Costs**

  New Jersey's Division of Motor Vehicles reported an expenditure of \$46,376,703 for inspection facilities (this value represents the annualized capital expenditure) and another annual operating expenditure of \$10,665,600 for inspection, adding up to \$57,042,303.

- **Calculation of Primary Sponsor's Revenues**

  The sponsor's costs are offset to a large degree by annual inspection revenues, which must be subtracted to avoid double counting. Annual inspection revenues are the same as the direct cost of inspection incurred by the users (C_2), which was calculated as \$20,339,447.

Reaching a Final Decision

Finally, a discount rate of 6% was deemed appropriate, because the state of New Jersey finances most state projects by issuing a 6% long-term tax-exempt bond. The streams of costs and benefits are already discounted so as to obtain their present and annual equivalent values.

From the state's estimates, the primary benefits of inspection are valued at \$217,689,486, compared with the primary disbenefits of inspection, which total \$145,886,225. Therefore, the user's net benefits are

$$\begin{aligned}\text{User's net benefits} &= \$217{,}689{,}486 - \$145{,}886{,}225\\ &= \$71{,}803{,}261.\end{aligned}$$

The sponsor's net costs are

$$\begin{aligned}\text{Sponsor's net costs} &= \$57{,}042{,}303 - \$20{,}339{,}447\\ &= \$36{,}702{,}856.\end{aligned}$$

Since all benefits and costs are expressed in annual equivalents, we can use these values directly to compute the degree of benefits that exceeds the sponsor's costs:

$$\$71{,}803{,}261 - \$36{,}702{,}856 = \$35{,}100{,}405 \text{ per year.}$$

This positive AE amount indicates that the New Jersey inspection system is economically justifiable. We can assume the AE amount would have been even greater had we also factored in secondary benefits. (For example, for simplicity, we have not explicitly considered vehicle growth in the state of New Jersey. For a complete analysis, this growth factor must be considered to account for all related benefits and costs in equivalence calculations.)

16.3.5 Difficulties Inherent in Public-Project Analysis

As we observed in the motor-vehicle inspection program in the previous section, public benefits are very difficult to quantify in a convincing manner. For example, consider the valuation of a saved human life in any category. Conceptually, the total benefit associated with saving a human life may include the avoidance of the insurance administration costs as well as legal and court costs. In addition, the average potential income lost because of premature death (taking into account age and sex) must be included. Obviously, the difficulties associated with any attempt to put precise numbers on human life are insurmountable.

Consider this example: A few years ago, a 50-year-old business executive was killed in a plane accident. The investigation indicated that the plane was not properly maintained according to federal guidelines. The executive's family sued the airline, and the court eventually ordered the airline to pay $5,250,000 to the victim's family. The judge calculated the value of the lost human life assuming that if the executive had lived and worked in the same capacity until his retirement, his remaining lifetime earnings would have been equivalent to $5,250,000 at the time of award. This is an example of how an individual human life was assigned a dollar value, but clearly any attempt to establish an average amount that represents the general population is controversial. We might even take exception to this individual case: Does the executive's salary adequately represent his worth to his family? Should we also assign a dollar value to their emotional attachment to him, and if so, how much?

Now consider a situation in which a local government is planning to widen a typical municipal highway to relieve chronic traffic congestion. Knowing that the project will be financed by local and state taxes, but that many out-of-state travelers also are expected to benefit, should the planner justify the project solely on the benefits to local residents? Which point of view should we take in measuring the benefits—the municipal level, the state level, or both? It is important that any benefit measure be performed from the appropriate *point of view*.

In addition to valuation and point-of-view issues, many possibilities for tampering with the results of benefit–cost analyses exist. Unlike private projects, many public projects are undertaken because of political pressure rather than on the basis of their economic benefits alone. In particular, whenever the benefit–cost ratio becomes marginal or less than unity, a potential to inflate the benefit figures to make the project look good exists.

16.4 Benefit–Cost Ratios

An alternative way of expressing the worthiness of a public project is to compare the user's benefits (B) with the sponsor's cost (C) by taking the ratio B/C. In this section, we shall define the benefit–cost (B/C) ratio and explain the relationship between it and the conventional NPW criterion.

16.4.1 Definition of Benefit–Cost Ratio

For a given benefit–cost profile, let B and C be the present values of benefits and costs defined respectively by

$$B = \sum_{n=0}^{N} b_n(1 + i)^{-n} \tag{16.2}$$

and

$$C = \sum_{n=0}^{N} c_n(1 + i)^{-n}, \tag{16.3}$$

where b_n = Benefit at the end of period n, $b_n \geq 0$,

c_n = Expense at the end of period n, $c_n \geq 0$,

$A_n = b_n - c_n$,

N = Project life, and

i = Sponsor's interest rate (discount rate).

The sponsor's costs (C) consist of the equivalent capital expenditure (I) and the equivalent annual operating costs (C') accrued in each successive period. (Note the sign convention we use in calculating a benefit–cost ratio. Since we are using a ratio, all benefits and cost flows are expressed in positive units. Recall that in previous equivalent-worth calculations our sign convention was to explicitly assign "+" for cash inflows and "−" for cash outflows.) Let's assume that a series of initial investments is required during the first K periods, while annual operating and maintenance costs accrue in each subsequent period. Then the equivalent present value for each component is

$$I = \sum_{n=0}^{K} c_n(1 + i)^{-n} \tag{16.4}$$

and

$$C' = \sum_{n=K+1}^{N} c_n(1 + i)^{-n}, \tag{16.5}$$

and $C = I + C'$.

The B/C ratio[8] is defined as

$$\mathrm{BC}(i) = \frac{B}{C} = \frac{B}{I + C'}, I + C' > 0. \tag{16.6}$$

If we are to accept a project, BC(i) must be greater than unity.

[8] An alternative measure, called the **net B/C ratio**, B'C(i), considers only the initial capital expenditure as a cash outlay, and annual net benefits are used:

$$\mathrm{B'C}(i) = \frac{B - C'}{I} = \frac{B'}{I}, I > 0.$$

The decision rule has not changed — the ratio must still be greater than one. It can be easily shown that a project with BC(i) > 1 will always have B′C(i) > 1, as long as both C and I are > 0, as they must be for the inequalities in the decision rules to maintain the stated senses. The magnitude of BC(i) will generally be different than that for B′C(i), but the magnitudes are irrelevant for making decisions. All that matters is whether the ratio exceeds the threshold value of one. However, some analysts prefer to use B′C(i) because it indicates the net benefit (B′) expected per dollar invested. But why do they care if the choice of ratio does not affect the decision? They may be trying to increase or decrease the magnitude of the reported ratio in order to influence audiences who do not understand the proper decision rule. People unfamiliar with benefit/cost analysis often assume that a project with a higher B/C ratio is better. This is not generally true, as is shown in 16.4.3. An incremental approach must be used to properly compare mutually exclusive alternatives.

Note that we must express the values of B, C', and I in present-worth equivalents. Alternatively, we can compute these values in terms of annual equivalents and use them in calculating the B/C ratio. The resulting B/C ratio is not affected.

EXAMPLE 16.1 Benefit–Cost Ratio

A public project being considered by a local government has the following estimated benefit–cost profile (Figure 16.4):

n	b_n	c_n	A_n
0		\$10	−\$10
1		10	−10
2	\$20	5	15
3	30	5	25
4	30	8	22
5	20	8	12

Assume that $i = 10\%$, $N = 5$, and $K = 1$. Compute B, C, I, C', and BC(10%).

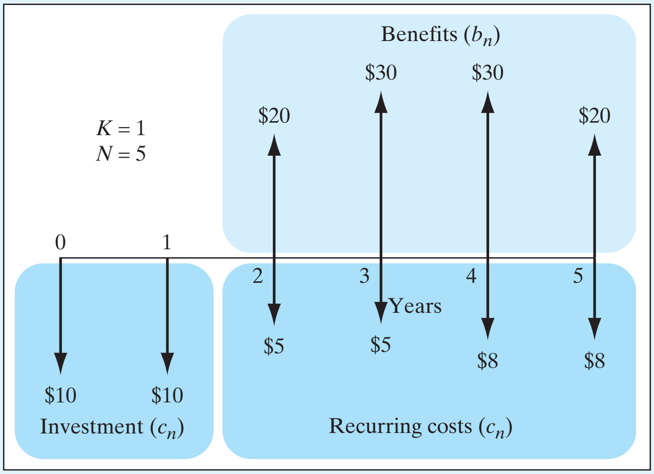


Figure 16.4 Classification of a project's cash flow elements (Example 16.1). Units are in millions of dollars.

SOLUTION

$$
\begin{aligned}
B &= \$20(P/F, 10\%, 2) + \$30(P/F, 10\%, 3) \\
&\quad + \$30(P/F, 10\%, 4) + \$20(P/F, 10\%, 5) \\
&= \$71.98; \\
C &= \$10 + \$10(P/F, 10\%, 1) + \$5(P/F, 10\%, 2)
\end{aligned}
$$

$$
\begin{aligned}
&\quad + \$5(P/F, 10\%, 3) + \$30(P/F, 10\%, 4) + \$20(P/F, 10\%, 5) \\
&= \$37.41; \\
I &= \$10 + \$10(P/F, 10\%, 1) \\
&= \$19.09; \\
C' &= C - I \\
&= \$18.32.
\end{aligned}
$$

Using Eq. (16.6), we can compute the B/C ratio as

$$
\begin{aligned}
\text{BC}(10\%) &= \frac{71.98}{\$19.09 + \$18.32} \\
&= 1.92 > 1.
\end{aligned}
$$

The B/C ratio exceeds unity, so the users' benefits exceed the sponsor's costs.

16.4.2 Relationship between *B/C* Ratio and NPW

The B/C ratio yields the same decision for a project as does the NPW criterion. Recall that the BC(i) criterion for project acceptance can be stated as

$$\frac{B}{I + C'} > 1. \tag{16.7}$$

If we multiply both sides of the equation by the term $(I + C')$ and transpose $(I + C')$ to the left-hand side, we have

$$B > (I + C'),$$

$$B - (I + C') > 0, \tag{16.8}$$

$$\text{PW}(i) = B - C > 0, \tag{16.9}$$

which is the same decision rule[9] as that which accepts a project by the NPW criterion. This implies that we could use the benefit–cost ratio in evaluating private projects instead of using the NPW criterion, or we could use the NPW criterion in evaluating public projects. Either approach will signal consistent project selection. Recall that, in Example 16.1, $\text{PW}(10\%) = B - C = \$34.57 > 0$; the project would thus be acceptable under the NPW criterion.

16.4.3 Comparing Mutually Exclusive Alternatives: Incremental Analysis

Let us now consider how we choose among mutually exclusive public projects. As we explained in Chapter 7, we must use the incremental investment approach in comparing alternatives based on any relative measure such as IRR or B/C.

[9] We can easily verify a similar relationship between the net B/C ratio and the NPW criterion.

Incremental Analysis Based on BC(i)

To apply incremental analysis, we compute the incremental differences for each term (B, I, and C') and take the B/C ratio on the basis of these differences. To use BC(i) on incremental investment, we may proceed as follows:

1. If one or more alternatives have B/C ratios greater than unity, eliminate any alternatives with a B/C ratio less than that.
2. Arrange the remaining alternatives in increasing order of the denominator $(I + C')$. Thus, the alternative with the smallest denominator should be the first (j), the alternative with the second smallest denominator should be second (k), and so forth.
3. Compute the incremental differences for each term (B, I, and C') for the paired alternatives (j, k) in the list:

$$\Delta B = B_k - B_j,$$

$$\Delta I = I_k - I_j,$$

$$\Delta C' = C'_k - C'_j.$$

4. Compute the BC(i) on incremental investment by evaluating

$$\text{BC}(i)_{k-j} = \frac{\Delta B}{\Delta I + \Delta C'}.$$

   If $\text{BC}(i)_{k-j} > 1$, select alternative k. Otherwise select alternative j.
5. Compare the alternative selected with the next one on the list by computing the incremental benefit–cost ratio.[10] Continue the process until you reach the bottom of the list. The alternative selected during the last pairing is the best one.

We may modify the foregoing decision procedure when we encounter the following situations:

- If $\Delta I + \Delta C' = 0$, we cannot use the benefit–cost ratio, because the equation implies that both alternatives require the same initial investment and operating expenditure. When this happens, we simply select the alternative with the largest B value.
- In situations where public projects with unequal service lives are to be compared, but the projects can be repeated, we may compute all component values (B, C', and I) on an annual basis and use them in incremental analysis.

EXAMPLE 16.2 Incremental Benefit–Cost Ratios

Consider three investment projects: A1, A2, and A3. Each project has the same service life, and the present worth of each component value (B, I, and C') is computed at 10% as follows:

[10] If we use the net B/C ratio as a basis, we need to order the alternatives in increasing order of I and compute the net B/C ratio on the incremental investment.

	Projects		
	A1	A2	A3
I	\$5,000	\$20,000	\$14,000
B	12,000	35,000	21,000
C'	4,000	8,000	1,000
PW(i)	\$3,000	\$7,000	\$6,000

(a) If all three projects are independent, which would be selected on the basis of BC(i)?

(b) If the three projects are mutually exclusive, which would be the best alternative? Show the sequence of calculations that would be required to produce the correct results. Use the B/C ratio on incremental investment.

SOLUTION

(a) Since $\text{PW}(i)_1$, $\text{PW}(i)_2$, and $\text{PW}(i)_3$ are positive, all of the projects are acceptable if they are independent. Also, the BC(i) values for each project are greater than unity, so the use of the benefit–cost ratio criterion leads to the same accept/reject conclusion as does the NPW criterion:

	A1	A2	A3
BC(i)	1.33	1.25	1.40

(b) If the projects are mutually exclusive, we must use the principle of incremental analysis. Obviously, if we attempt to rank the projects according to the size of the B/C ratio, we will observe a different project preference. For example, if we use the BC(i) on the total investment, we see that A3 appears to be the most desirable and A2 the least desirable, but selecting mutually exclusive projects on the basis of B/C ratios is incorrect. Certainly, with $\text{PW}(i)_2 > \text{PW}(i)_3 > \text{PW}(i)_1$, Project A2 would be selected under the NPW criterion. By computing the incremental B/C ratios, we will select a project that is consistent with that criterion.

We will first arrange the projects in increasing order of their denominators $(I + C')$ for the BC(i) criterion:[11]

Ranking Base	A1	A3	A2
$I + C'$	\$9,000	\$15,000	\$28,000

[11] I is used as a ranking base for the $B'C(i)$ criterion. The order still remains unchanged: A1, A3, and A2.

- **A1 versus A3.** With the do-nothing alternative, we first drop from consideration any project that has a B/C ratio smaller than unity. In our example, the B/C ratios of all three projects exceed unity, so the first incremental comparison is between A1 and A3:

$$\begin{aligned} \text{BC}(i)_{3-1} &= \frac{\$21{,}000 - \$12{,}000}{(\$14{,}000 - \$5{,}000) + (\$1{,}000 - \$4{,}000)} \\ &= 1.51. \end{aligned}$$

  Since the ratio is greater than unity, we prefer A3 to A1. Therefore, A3 becomes the "current best" alternative.

- **A3 versus A2.** Next, we must determine whether the incremental benefits to be realized from A2 would justify the additional expenditure. Therefore, we need to compare A2 and A3 as follows:

$$\begin{aligned} \text{BC}(i)_{2-3} &= \frac{\$35{,}000 - \$21{,}000}{(\$20{,}000 - \$14{,}000) + (\$8{,}000 - \$1{,}000)} \\ &= 1.081. \end{aligned}$$

  The incremental B/C ratio again exceeds unity; therefore, we prefer A2 over A3. With no further projects to consider, A2 becomes our final choice.[12]

16.5 Analysis of Public Projects Based on Cost-Effectiveness

In evaluating public investment projects, we may encounter situations where competing alternatives have the same goals, but the effectiveness with which those goals can be met may or may not be measurable in dollars. In these situations, we compare decision alternatives directly on the basis of their **cost-effectiveness**. Here, we judge the effectiveness of an alternative in dollars or some nonmonetary measure by the extent to which that alternative, if implemented, will attain the desired objective. The preferred alternative is then either the one that produces the maximum effectiveness for a given level of cost or the one that produces the minimum cost for a fixed level of effectiveness.

[12] Note that if we had to use the net B/C ratio on this incremental investment decision, we would obtain the same conclusion. Since all $B'C(i)$ ratios exceed unity, no do-nothing alternative exists. By comparing the first pair of projects on this list, we obtain

$$\begin{aligned} \text{B}'\text{C}(i)_{3-1} &= \frac{(\$21{,}000 - \$12{,}000) - (\$1{,}000 - \$4{,}000)}{(\$14{,}000 - \$5{,}000)} \\ &= 1.331. \end{aligned}$$

Accordingly, Project A3 becomes the "current best." Next, a comparison of A2 and A3 yields

$$\begin{aligned} \text{B}'\text{C}(i)_{2-3} &= \frac{(\$35{,}000 - \$21{,}000) - (\$8{,}000 - \$1{,}000)}{(\$20{,}000 - \$14{,}000)} \\ &= 1.171. \end{aligned}$$

Therefore, A2 becomes the best choice by the net B/C ratio criterion.

16.5.1 Cost-Effectiveness Studies in the Public Sector

A typical cost-effectiveness analysis procedure in the public sector involves the following steps:

Step 1. Establish the goals to be achieved by the analysis.
Step 2. Identify the restrictions imposed on achieving the goals, such as those having to do with the budget or with weight.
Step 3. Identify all the feasible alternatives for achieving the goals.
Step 4. Identify the social interest rate to use in the analysis.
Step 5. Determine the equivalent life-cycle cost of each alternative, including R&D costs, testing costs, capital investment, annual operating and maintenance costs, and the salvage value of the item under consideration.
Step 6. Determine the basis for developing the cost-effectiveness index. Two approaches may be used: (1) the fixed-cost approach and (2) the fixed-effectiveness approach. If the fixed-cost approach is used, determine the amount of effectiveness obtained at a given cost. If the fixed-effectiveness approach is used, determine the cost required to obtain the predetermined level of effectiveness.
Step 7. Compute the cost-effectiveness ratio for each alternative, based on the criterion selected in Step 6.
Step 8. Select the alternative with the maximum cost-effective index.

When either the cost or the level of effectiveness is clearly stated in achieving the declared program objective, most cost-effectiveness studies will be relatively straightforward. If that is not the case, however, the decision maker must come up with his or her own program objective by fixing either the cost required in the program or the level of effectiveness to be achieved. The next section shows how such a problem can easily evolve in many public projects or military applications.

16.5.2 A Cost-Effectiveness Case Study[13]

To illustrate the procedures involved in cost-effectiveness analysis, we shall present an example of how the U.S. Army selected the most cost-effective program for providing on-time delivery of time-sensitive, high-priority cargos and key personnel to the battle staging grounds.

Statement of the Problem

The U.S. Army has been engaged in recent conflicts that have transformed from the traditional set-piece battles into operations in distributed locations that require rapid sequences of activities. To support success in these new operations, the Army needs timely delivery of cargos and personnel in the distributed locations. Consequently, the dispersion of forces has created a condition of unsecured land lines of communication (LOC), and aerial delivery is considered as one of the practical solutions to the problem. The time-sensitive nature of these priority cargos makes it most preferable to have direct delivery from intermediate staging bases (ISB) to the forward brigade combat teams (BCT).

[13] This case study is provided by Dr. George C. Prueitt of CAS, Inc. All numbers used herein do not represent the actual values used by the U.S. Army.

The transportation network typically involves a long-haul move (a fixed-wing aerial movement), and a short-haul distribution (by helicopter or truck). The long-haul usually stops at the closest supporting airfield, but with the appropriate asset, a single, direct movement could be made. The long-haul portion has been the bigger problem—trucks take too long and are vulnerable to hostilities; the U.S. Air Force (USAF) assets are not always available or appropriate; and existing helicopters do not have the necessary range to fly. Further, the use of the larger USAF aircraft results in inefficient load, as the high-priority cargos use only a small fraction of the capacity of the aircraft. The Army is investigating how to best correct the problem. They are considering three options to handle the long haul: (1) Use the U.S. Air Force (C-130J) assets; (2) procure a commercially available Future Cargo Aircraft (FCA); or (3) use additional helicopters (CH-47).

Defining the Goals

The solution will be a "best value" selection, providing the best capability for the investment required. The selection process must address three operational perspectives.

- First, a "micro" examination: For a given specific battlefield arrangement (available transportation network, supported organizations and locations), the decision metric is the time required to delivery specific critical cargos and the solutions' comparative operating costs. This metric is a suitability measure, to identify the system that best, most quickly, meets the timely delivery requirement.
- Second, a "macro" examination: Given a broader, more prolonged theater support requirement, the decision metric becomes what percentage of critical cargos can be delivered, and what is the cost of procuring all the transportation assets needed to create the delivery network combinations (fixed-wing airplanes, helicopters, and trucks) to meet those delivery percentages. This metric is a feasibility measure to determine the number of assets needed to meet the quantities of cargos to be delivered.
- Third, given relatively comparable fixed-wing aircraft fleets (differing quantities for equal capability), what are the 15-year life-cycle costs associated with those alternatives? This is an affordability metric, to ensure that all life-cycle costs are properly identified and can be met within the Army budget.

Description of Alternatives

As mentioned earlier, the Army is considering three alternatives. They are:

- **Alternative 1—use the USAF C-130J assets.** The USAF C-130J aircraft has been proposed as an alternative for the long-haul task. The C-130J is a new acquisition, and will be considered in two employment concepts: first, in a direct movement pattern, and second, as part of a standard USAF Scheduled Tactical Air Re-supply (STAR) route (analogous to a bus route). Current operations almost exclusively use the STAR route method when C-130 aircraft are employed. It is assumed that transportation planning and theater priorities would be sufficiently high to permit the C-130J to be employed in the more direct delivery method, and not limited solely to STAR route operations.
- **Alternative 2—use future cargo aircraft.** Another long-haul alternative is to procure one of two commercially available products capable of delivering these cargos on a timely and efficient basis.

- **Alternative 3—use additional C-47 helicopters.** Looking first at the long-haul task, most of today's deliveries are provided by either the CH-47 helicopter or the C-130 aircraft in conjunction with another vehicle. The CH-47 is being used to perform this mission because it is the "best available" Army asset. Unfortunately, it is expensive to operate, and its range limitations make it an inefficient method of carrying out the mission. Further, the long distances between the ISB to the forward units are causing the helicopters to accumulate flight hours more rapidly than planned in their service-life projections, and this has generated a significant increase in their maintenance requirements.

These long-haul delivery alternatives are described in Table 16.6.

In addition to the long-haul task, the shorter delivery distribution legs will usually need a complementary ground or helicopter asset to make the final delivery when the fixed-wing assets cannot land close enough to the BCT, because of a lack of improved landing strips or runways of sufficient length. This creates a greater burden on the transportation network to ensure that adequate ground or rotary-wing assets are available to complete the mission. The combinations of long-haul alternatives and final delivery systems create the series of network transportation options described in Table 16.7.

TABLE 16.6 **Descriptions of Alternatives for Transportation Network Long-Haul Requirement**

Alternative	Description	Comment
Alternative 1—C-130J	Procure additional C-130Js and maximize their use to perform the long-haul task of the intra-theater delivery of critical, time-sensitive cargo and key personnel. Minimize requirement for additional CH-47s.	C-130Js will use both USAF Scheduled Tactical Air Re-supply (STAR) routes and more direct routes. The C-130J has longer run way requirements than smaller FCA aircraft does.
Alternative 2—Army FCA	Procure a variant of the FCA and maximize its use to perform the long-haul task of the intratheater delivery of mission-critical, time-sensitive cargo and key personnel, with minimal use of CH-47s.	In some situations, the FCA will be able to land either closer to or at the BCT locations. Two versions of the FCA (Alternative 2A and Alternative 2B) have been included in this examination.
Alternative 3—More CH-47s	Procure additional CH-47s to perform the long-haul task of the intratheater delivery of critical, time-sensitive cargo and key personnel.	This alternative will include those additional CH-47s needed to carry support systems for the CH-47s that are used to move cargo over extended distances.

TABLE 16.7 Descriptions of Transportation Network Options

Network Option (NO_i)	Description
NO_1	ALT 1 (C-130) direct from ISB to C-130 Supportable Forward Airfield,
NO_2	ALT 1 (C-130) direct from ISB to C-130 Supportable Forward Airfield, then CH-47 to BCT
NO_3	ALT 1 (C-130) STAR route from ISB to C-130 Supportable Forward Airfield (stop nearest to BCT), then truck to BCT
NO_4	ALT 1 (C-130) STAR route from ISB to C-130 Supportable Forward Airfield (stop nearest to BCT), then CH-47 to BCT
NO_5	ALT 2A direct from ISB to FCA Supportable Forward Airfield, then truck to BCT
NO_6	ALT 2A direct from ISB to FCA Supportable Forward Airfield, then CH-47 to BCT
NO_7	ALT 2A direct from ISB to BCT
NO_8	ALT 2B direct from ISB to FCA Supportable Forward Airfield, then truck to BCT
NO_9	ALT 2B direct from ISB to FCA Supportable Forward Airfield, then CH-47 to BCT
NO_{10}	ALT 2B direct from ISB to BCT
NO_{11}	ALT 3 (CH-47) direct from ISB to BCT, with multiple refueling stops en route

Figure 16.5 provides a descriptive portrayal of these transportation network options.

Micro Analysis

To perform a cost-effectiveness analysis, the micro comparisons were made by selecting the delivery time as the performance metric (vertical axis in Figure 16.6), and one-way operating cost as the other metric (horizontal axis). Lower cost and shorter delivery times cause the direction of preference to be in the lower left-hand corner of the figure. The respective operating costs for each system were: C-130J at \$3,850 per flight hour, FCA 2A at \$2,800, FCA 2B at \$1,680, and CH-47 at \$4,882. Transportation network option 10 (NO_{10}), based on Alternative 2B FCA, and NO_7, based on Alternative 2A FCA, with each flying directly from ISB to BCT, had the shortest times to accomplish the mission. Their respective operating costs pushed them into the most favored regions on the graph. Not surprisingly, the next quickest option was NO_2, based on Alternative 1 aircraft flying directly to a C-130 Supportable Forward Airfield, with a CH-47 delivering for the last leg; however, the higher operating costs of the C-130J (over the FCA alternatives) and the CH-47 made its operating cost more than double NO_{10}. For the remaining options, NO_3 and NO_4, using the C-130J on a

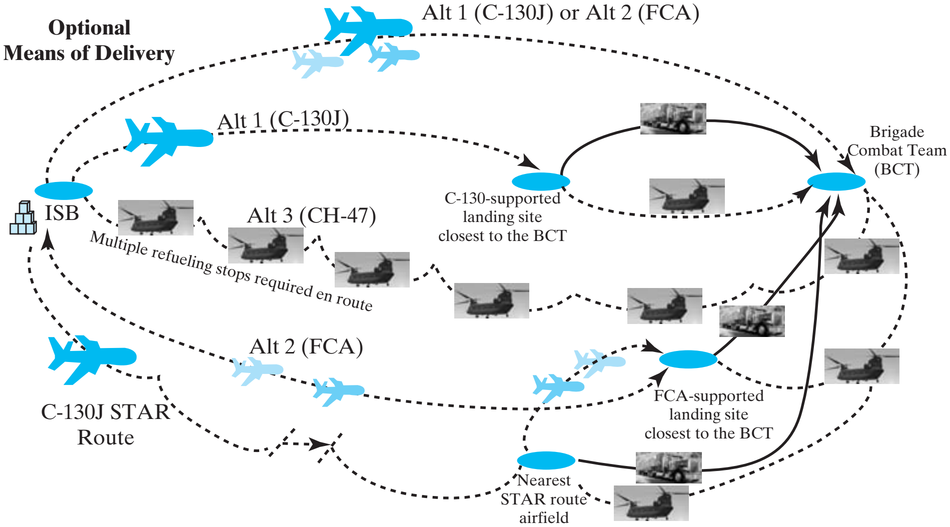


Figure 16.5 Transportation network option schematics.

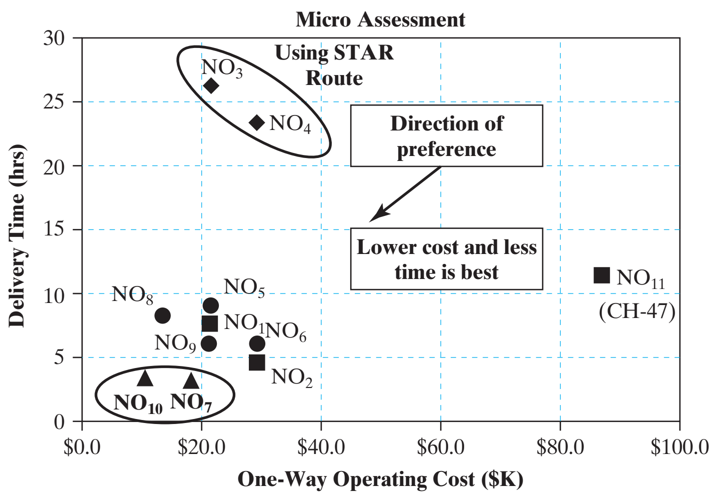


Figure 16.6 Assessment results from micro cost-effectiveness analysis.

STAR route, required the longest delivery time, although the operating costs were comparable to the most favored solutions. NO_{11}, the CH-47–based option, had the highest operating costs. Figure 16.6 summarizes the results for all 11 transportation network options.

Macro Analysis

The macro analysis was performed with the criterion of capability to deliver high-priority cargos in two simultaneous combat operations over a 30-day period. The minimum acceptable on-time delivery rate is 80% of all required shipments. The requirements were derived from one operation with 10 days of high-intensity combat, followed by 20 days of stability operations, and a second operation consisting of 30 days of low-intensity stability operations. Current transportation asset allocations were used to establish a "baseline" capability. The baseline included 28 CH-47 helicopters and 10 C-130J aircraft for this specific mission, and additional quantities of Army systems (other aircraft and trucks) to do the final cargo distributions. These assets were capable of satisfying about 12% of the total on-time delivery requirement. The shortfall between 12% and the 80% standard represents the capability "gap" that additional assets are required to fill.

To complete the macro analysis, additional quantities of Alternatives 1, 2A, 2B, and 3 were incrementally added, and the resultant increase in on-time deliveries was computed. The cost to procure the additional quantities was determined with the following unit prices: Alternative 1 at \$75.6M each, Alternative 2A at \$34.5M, Alternative 2B at \$29.2M, and Alternative 3 at \$26.1M. Figure 16.7 shows the changes in percent-on-time delivery versus the procurement cost of the respective alternatives. There is a significant procurement cost differentialy between alternatives, with Alternatives 2A and 2B being the most cost effective.

Life-Cycle Cost for Each Alternative

The third part of the case study is to perform the life-cycle cost (LCC) analysis for the various alternatives. Table 16.8 lists the cost items that are considered in this LCC analysis.

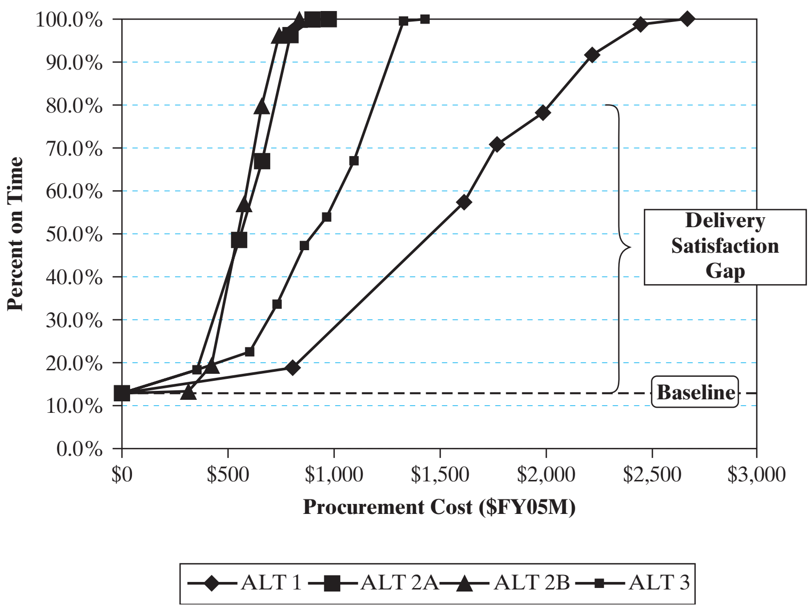


Figure 16.7 Assessment results from macro effectiveness analysis.

TABLE 16.8 **Definitions of Life-Cycle Cost Variables**

Life-Cycle Cost Element	Cost Variable	Description
1	RDT&E	Government and contractor costs associated with the research, development, test, and evaluation (RDT&E) of the material system.
2	Procurement	Costs resulting from the production and initial fielding of the material system in the Army's operational inventory.
3	Military construction	Cost of all military construction projects associated with a material system. No military construction money is anticipated to be needed for any of the FCA alternatives.
4	Military personnel	Cost of military personnel associated with the development and operation of the material system.
5	O&M	O&M funded cost associated with development, production, fielding, operation, and support of the material system for 20 years.

In fact, these cost items represent the common decision elements mandated by the U.S. Department of Defense, along with appropriate rules and assumptions, to ensure that each alternative be evaluated for comparable cost and affordability. First, an LCC estimate was developed for specific quantities of each primary long-haul aircraft in the alternatives. The number of aircraft was chosen to establish equal fleet capabilities (not necessarily fleet size). Second, to determine the number of aircraft required for each alternative, the U.S. Army used the equal-effectiveness standard of 80% on-time delivery of high-priority cargo and key personnel. Specifically,

- Alternatives 2A and 2B use a fleet size of 56, as derived from the macro analysis and with additional fleet support considerations.
- Alternative 1, the USAF C-130J, uses 40 aircraft, because it was assumed that all additional fleet support requirements would be addressed with the USAF larger program. Similarly,
- Alternative 3 uses 92 CH-47F as its mission requirement, with no additional fleet support requirements, as the 92 would be added to the existing fleet of about 400 CH-47 aircraft.

Cost estimates were developed for the respective alternatives. In a simple form, these estimates provide the future estimated costs for procurement and operations. The procurement costs include both RDT&E and procurement requirements. The operating cost includes operations and maintenance (O&M) and military personnel costs. There were some nominal military construction costs, but they were equal for all alternatives. A 15-year operating cycle (from first procurement through last operation) was assumed in developing the cost estimates. The projected costs for future years are provided in Table 16.9.

TABLE 16.9 **Life-Cycle Cost Estimates for Each Alternative**

	ALT 1		ALT 2A		ALT 2B		ALT 3	
Year	**Proc**	**Operating**	**Proc**	**Operating**	**Proc**	**Operating**	**Proc**	**Operating**
1	$702.80	$ 25.0	$257.5	$ 4.8	$221.1	$ 3.3	$620.2	$ 10.8
2	$860.27	$ 56.1	$529.9	$ 14.7	$450.3	$ 12.5	$654.4	$ 82.0
3	$877.47	$ 88.4	$800.8	$ 43.0	$687.2	$ 35.0	$451.4	$163.2
4	$447.51	$122.0	$431.3	$ 64.0	$376.1	$ 52.6	$145.2	$224.1
5	$ 0.00	$151.6	$206.1	$105.1	$189.2	$ 80.7	$351.0	$251.4
6	$ 0.00	$154.7	$ 0.0	$114.3	$ 0.0	$ 80.5	$262.6	$258.8
7	$ 0.00	$157.8	$ 0.0	$120.6	$ 0.0	$ 81.5	$ 0.0	$262.3
8	$ 0.00	$160.9	$ 0.0	$128.4	$ 0.0	$ 86.8	$ 0.0	$274.7
9	$ 0.00	$164.1	$ 0.0	$132.2	$ 0.0	$ 90.5	$ 0.0	$287.5
10	$ 0.00	$167.4	$ 0.0	$139.9	$ 0.0	$ 95.6	$ 0.0	$301.2
11	$ 0.00	$170.8	$ 0.0	$141.4	$ 0.0	$ 98.3	$ 0.0	$315.5
12	$ 0.00	$174.2	$ 0.0	$145.8	$ 0.0	$102.5	$ 0.0	$324.4
13	$ 0.00	$145.8	$ 0.0	$129.6	$ 0.0	$106.5	$ 0.0	$362.1
14	$ 0.00	$110.0	$ 0.0	$119.8	$ 0.0	$ 89.6	$ 0.0	$248.8
15	$ 0.00	$ 72.6	$ 0.0	$106.2	$ 0.0	$ 77.6	$ 0.0	$ 86.7
16	$ 0.00	$ 33.6	$ 0.0	$100.9	$ 0.0	$ 74.2	$ 0.0	$ 35.4

Notes: All costs are $M.
"Proc" means procurement cost estimate.
"Operating" includes operations, maintenance, and manpower costs.

For most of the procurements by the U.S. Department of Defense, future inflation factors must be specified in the analysis. For this case study, an annual inflation rate of 2% was used. In terms of interest rate, an inflation-adjusted discount rate of 8% was used to calculate the LCC for each alternative, which is summarized in Table 16.10.

Figure 16.8 illustrates the cost component of each alternative's LCC. The figure shows that Alternatives 2A and 2B, at 56 aircraft, have both lower procurement and operations and maintenance costs than either Alternative 1, the C-130J alternative, for its quantity of 40 aircraft, or Alternative 3, the CH-47F alternative, based on 92 helicopters. As anticipated earlier, the CH-47F alternative turns out to be the most expensive option due to its higher operating costs, even though its procurement of 92 helicopters is less expensive than 40 C-130J aircraft. The total operating costs differ in contribution by type of aircraft. The fixed-wing aircraft estimates are based on 600 hours of flying time per year, while the helicopters are scheduled for less than

TABLE 16.10 Present Value of Life-Cycle Cost for Each Alternative

Year	ALT 1		ALT 2A		ALT 2B		ALT 3	
	Proc	Operating	Proc	Operating	Proc	Operating	Proc	Operating
0	$ 702.8	$ 25.0	$ 257.5	$ 4.8	$ 221.1	$ 3.3	$ 620.2	$ 10.8
1	$ 796.5	$ 51.9	$ 490.6	$ 13.6	$ 417.0	$ 11.6	$ 606.0	$ 75.9
2	$ 752.3	$ 75.8	$ 686.6	$ 36.8	$ 589.1	$ 30.0	$ 387.0	$ 140.0
3	$ 355.2	$ 96.9	$ 342.4	$ 50.8	$ 298.6	$ 41.8	$ 115.2	$ 177.9
4	$ 0.0	$ 111.5	$ 151.5	$ 77.3	$ 139.1	$ 59.4	$ 258.0	$ 184.8
5	$ 0.0	$ 105.3	$ 0.0	$ 77.8	$ 0.0	$ 54.8	$ 178.7	$ 176.1
6	$ 0.0	$ 99.4	$ 0.0	$ 76.0	$ 0.0	$ 51.4	$ 0.0	$ 165.3
7	$ 0.0	$ 93.9	$ 0.0	$ 74.9	$ 0.0	$ 50.7	$ 0.0	$ 160.3
8	$ 0.0	$ 88.7	$ 0.0	$ 71.4	$ 0.0	$ 48.9	$ 0.0	$ 155.3
9	$ 0.0	$ 83.8	$ 0.0	$ 70.0	$ 0.0	$ 47.8	$ 0.0	$ 150.7
10	$ 0.0	$ 79.1	$ 0.0	$ 65.5	$ 0.0	$ 45.5	$ 0.0	$ 146.1
11	$ 0.0	$ 74.7	$ 0.0	$ 62.6	$ 0.0	$ 43.9	$ 0.0	$ 139.1
12	$ 0.0	$ 57.9	$ 0.0	$ 51.5	$ 0.0	$ 42.3	$ 0.0	$ 143.8
13	$ 0.0	$ 40.4	$ 0.0	$ 44.0	$ 0.0	$ 33.0	$ 0.0	$ 91.5
14	$ 0.0	$ 24.7	$ 0.0	$ 36.2	$ 0.0	$ 26.4	$ 0.0	$ 29.5
15	$ 0.0	$ 10.6	$ 0.0	$ 31.8	$ 0.0	$ 23.4	$ 0.0	$ 11.2
Subtotal	$2,606.9	$1,119.6	$1,928.5	$ 845.0	$1,664.9	$ 614.1	$2,165.1	$1,958.3
ALT Total		$3,726.5		$2,773.5		$2,278.9		$4,123.4

Notes: 1. All figures are in $M.

2. Sample calculation:

$$\begin{aligned}\text{ALT 1 Present Value } (8\%) &= (\$702.8 + \$25.0) + (\$796.5 + 51.9)(P/F, 8\%, 1) \\ &\quad + \ldots + \$10.6(P/F, 8\%, 15) \\ &= \$3{,}726.5\text{M}.\end{aligned}$$

200 hours of flying time. However, because the airspeed and flying range for the helicopter are much lower than for the fixed-wing aircraft, more CH-47F helicopters are required to provide the same level of capability. Alternative 1, using the C-130J as the primary aircraft, requires fewer total aircraft than Alternatives 2A and 2B, but with nearly twice the unit cost, it is a more expensive option. In conclusion, for the alternatives considered, the commercially available candidates for the FCA (Alternatives 2A and 2B) provide the best opportunity for the Army to satisfy its requirement to delivery of mission-critical, time-sensitive cargo and key personnel from an ISB directly to a BCT, with Alternative 2B having a slight edge over 2A, for the metrics used.

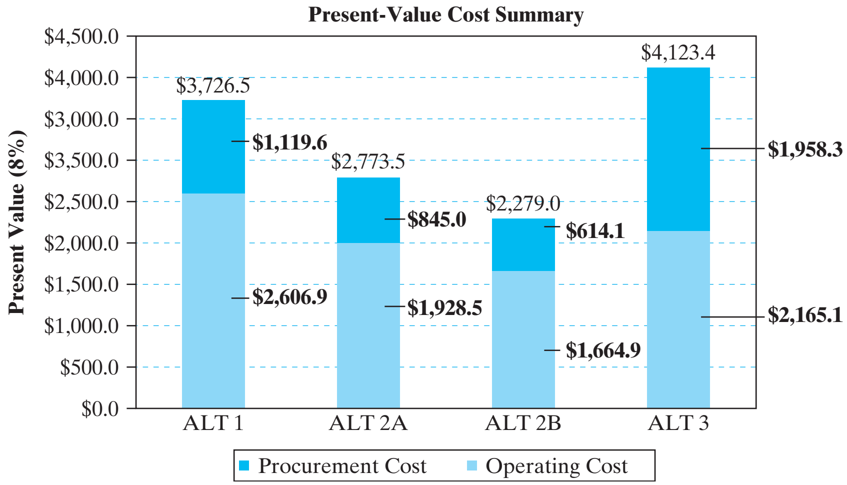


Figure 16.8 Alternatives' present value (8%) for procurement and operations.

SUMMARY

- The service sector accounts for about 80% of U.S. GDP. Health care and government services account for almost 30% of the total GDP.
- In health economics, cost-effectiveness analysis is the most widely used economic evaluation method. The cost-effectiveness ratio is defined as

$$\text{Cost-effectiveness ratio} = \frac{\sum(\text{all costs})}{\sum(\text{all measured health effects})}$$

  If independent intervention programs are evaluated, we can rank the programs on the basis of their cost-effectiveness ratios and accept as many programs as the budget permits. When we compare mutually exclusive intervention programs, the incremental cost-effectiveness ratio should be used to determine whether an additional cost can be justified to increase health effects.

- **Benefit–cost analysis** is commonly used to evaluate public projects; several facets unique to public-project analysis are neatly addressed by benefit–cost analysis:

  1. Benefits of a nonmonetary nature can be quantified and factored into the analysis.
  2. A broad range of project users distinct from the sponsor can and should be considered; benefits and disbenefits to *all* these users can and should be taken into account.

- Difficulties involved in public-project analysis include the following:

  1. Identifying all the users of the project.
  2. Identifying all the benefits and disbenefits of the project.

3. Quantifying all the benefits and disbenefits in dollars or some other unit of measure.
4. Selecting an appropriate interest rate at which to discount benefits and costs to a present value.

- The B/C ratio is defined as

$$\text{BC}(i) = \frac{B}{C} = \frac{B}{I + C'}, I + C' > 0.$$

The decision rule is that if $\text{BC}(i) \geq 1$, then the project is acceptable.

- The net B/C ratio is defined as

$$\text{B}'\text{C}(i) = \frac{B - C'}{I} = \frac{B'}{I}, I > 0.$$

The net B/C ratio expresses the net benefit expected per dollar invested. The same decision rule applies as for the B/C ratio.

- The **cost-effectiveness method** allows us to compare projects on the basis of cost and nonmonetary effectiveness measures. We may either maximize effectiveness for a given cost criterion or minimize cost for a given effectiveness criterion.

PROBLEMS

Cost-Effectiveness Analysis

16.1 The following table summarizes the costs of treatment of a disease, based on two different antibiotics and associated health benefits (effectiveness):

Which treatment option is the best?

Type of Treatment	Cost of Treating 100 Patients	Effectiveness (Percent Successful Treatment of Infections)
Antibiotic A	\$12,000	75%
Antibiotic B	\$13,500	80%
Antibiotic C	\$14,800	82%

16.2 The Table P16.2 summarizes cervical cancer treatment options and their health effectiveness. Find the best strategy for treating cervical cancer.

TABLE P16.2 A CEA Examining Three Strategies

Strategy	Cost	Marginal Cost	Effectiveness	Marginal Effectiveness	CE Ratio
Nothing	\$0	—	0 years	—	—
Simple	\$5,000	\$5,000	5 years	5 years	\$1,000/yr
Complex	\$50,000	\$45,000	5.5 years	0.5 years	\$90,000/yr

Valuation of Benefits and Costs

16.3 The state of Michigan is considering a bill that would ban the use of road salt on highways and bridges during icy conditions. Road salt is known to be toxic, costly, corrosive, and caustic. Chevron Chemical Company produces a calcium magnesium acetate (CMA) deicer and sells it for $600 a ton as Ice-B-Gon. Road salts, by contrast, sold for an average of $14 a ton in 1995. Michigan needs about 600,000 tons of road salt each year. (The state spent $9.2 million on road salt in 1995.) Chevron estimates that each ton of salt on the road costs $650 in highway corrosion, $525 in rust on vehicles, $150 in corrosion to utility lines, and $100 in damages to water supplies, for a total of $1,425. Unknown salt damage to vegetation and soil surrounding areas of highways has occurred. Michigan would ban road salt (at least on expensive steel bridges or near sensitive lakes) if state studies support Chevron's cost claims.

(a) What would be the users' benefits and sponsor's costs if a complete ban on road salt were imposed in Michigan?

(b) How would you go about determining the salt damages (in dollars) to vegetation and soil?

16.4 A public school system in Ohio is considering the adoption of a four-day school week as opposed to the current five-day school week in high schools. The community is hesitant about the plan, but the superintendent of the school system envisions many benefits associated with the four-day system, Wednesday being the "day off." The following pros and cons have been cited:

- Experiments with the four-day system indicate that the "day off" in the middle of the week will cut down on both teacher and pupil absences.
- The longer hours on school days will require increased attention spans, which is not an appropriate expectation for younger children.
- The reduction in costs to the federal government should be substantial, as the number of lunches served would be cut by approximately 20%.
- The state bases its expenditures on its local school systems largely on the average number of pupils attending school in the system. Since the number of absences will decrease, state expenditures on local systems should increase.
- Older students might want to work on Wednesdays. Unemployment is a problem in this region, however, and any influx of new job seekers could aggravate an existing problem. Community centers, libraries, and other public areas also may experience increased usage on Wednesdays.
- Parents who provide transportation for their children will see a savings in fuel costs. Primarily, only those parents whose children live less than 2 miles from the school would be involved. Children living more than 2 miles from school are eligible for free transportation provided by the local government.
- Decreases in both public and private transportation should result in fuel conservation, decreased pollution, and less wear on the roads. Traffic congestion should ease on Wednesdays in areas where congestion caused by school traffic is a problem.
- Working parents will be forced to make child-care arrangements (and possibly payments) for one weekday per week.
- Students will benefit from wasting less time driving to and from school; Wednesdays will be available for study, thus taking the heavy demand off most nights. Bused students will spend far less time per week waiting for buses.

- The local school board should see some ease in funding problems. The two areas most greatly affected are the transportation system and nutritional programs.
  - (a) For this type of public study, what do you identify as the users' benefits and disbenefits?
  - (b) What items would be considered as the sponsor's costs?
  - (c) Discuss any other benefits or costs associated with the four-day school week.

16.5 The Electric Department of the City of Tallahassee, Florida, operates generating and transmission facilities serving approximately 140,000 people in the city and surrounding Leon County. The city has proposed the construction of a $300 million, 235-MW circulating fluidized-bed combustor (CFBC) at Arvah B. Hopkins Station to power a turbine generator that is currently receiving steam from an existing boiler fueled by gas or oil. Among the advantages associated with the use of CFBC systems are the following:

- A variety of fuels can be burned, including inexpensive low-grade fuels with high ash and a high sulfur content.
- The relatively low combustion temperatures inhibit the formation of nitrogen oxides. Acid-gas emissions associated with CFBC units would be expected to be significantly lower than emissions from conventional coal-fueled units.
- The sulfur-removal method, low combustion temperatures, and high-combustion efficiency characteristic of CFBC units result in solid wastes, which are physically and chemically more amenable to land disposal than the solid wastes resulting from conventional coal-burning boilers equipped with flue-gas desulfurization equipment.

On the basis of the Department of Energy's (DOE's) projections of growth and expected market penetration, the demonstration of a successful 235-MW unit could lead to as much as 41,000 MW of CFBC generation being constructed by the year 2010. The proposed project would reduce the city's dependency on oil and gas fuels by converting its largest generating unit to coal-fuel capability. Consequently, substantial reductions in local acid-gas emissions could be realized in comparison to the permitted emissions associated with oil fuel. The city has requested a $50 million cost share from the DOE. Under the Clean Coal Technology Program, cost sharing is considered attractive because the DOE cost share would largely offset the risk of using such a new technology. To qualify for cost-sharing money, the city has to address the following questions for the DOE:

(a) What is the significance of the project at local and national levels?
(b) What items would constitute the users' benefits and disbenefits associated with the project?
(c) What items would constitute the sponsor's costs?

Put yourself in the city engineer's position, and respond to these questions.

Benefit–Cost Analyses

16.6 A city government is considering two types of town-dump sanitary systems. Design A requires an initial outlay of $400,000, with annual operating and maintenance costs of $50,000 for the next 15 years; design B calls for an investment of $300,000, with annual operating and maintenance costs of $80,000 per year for the next 15 years. Fee collections from the residents would be \$85,000 per year. The interest rate is 8%, and no salvage value is associated with either system.

(a) Using the benefit–cost ratio BC(i), which system should be selected?

(b) If a new design (design C), which requires an initial outlay of \$350,000 and annual operating and maintenance costs of \$65,000, is proposed, would your answer in (a) change?

16.7 The U.S. government is considering building apartments for government employees working in a foreign country and living in locally owned housing. A comparison of two possible buildings indicates the following:

	Building X	Building Y
Original investment by government agencies	\$8,000,000	\$12,000,000
Estimated annual maintenance costs	240,000	180,000
Savings in annual rent now being paid to house employees	1,960,000	1,320,000

Assume the salvage or sale value of the apartments to be 60% of the first investment. Use 10% and a 20-year study period to compute the B/C ratio on incremental investment, and make a recommendation. (Assume no do-nothing alternative.)

16.8 Three public-investment alternatives with the same service life are available: A1, A2, and A3. Their respective total benefits, costs, and first costs are given in present worth as follows:

	Proposals		
Present worth	A1	A2	A3
I	100	300	200
B	400	700	500
C'	100	200	150

Assuming no do-nothing alternative, which project would you select on the basis of the benefit–cost ratio BC(i) on incremental investment?

16.9 A local city that operates automobile parking facilities is evaluating a proposal that it erect and operate a structure for parking in the city's downtown area. Three designs for a facility to be built on available sites have been identified (all dollar figures are in thousands):

	Design A	Design B	Design C
Cost of site	$240	$180	$200
Cost of building	2,200	700	1,400
Annual fee collection	830	750	600
Annual maintenance cost	410	360	310
Service life	30 years	30 years	30 years

At the end of the estimated service life, whichever facility had been constructed would be torn down, and the land would be sold. It is estimated that the proceeds from the resale of the land will be equal to the cost of clearing the site. If the city's interest rate is known to be 10%, which design alternative would be selected on the basis of the benefit–cost criterion?

16.10 The federal government is planning a hydroelectric project for a river basin. In addition to producing electric power, this project will provide flood control, irrigation, and recreation benefits. The estimated benefits and costs expected to be derived from the three alternatives under consideration are listed in the following table:

	Decision Alternatives		
	A	B	C
Initial cost	$8,000,000	$10,000,000	$15,000,000
Annual benefits or costs:			
Power sales	$1,000,000	$1,200,000	$1,800,000
Flood control savings	250,000	350,000	500,000
Irrigation benefits	350,000	450,000	600,000
Recreation benefits	100,000	200,000	350,000
O&M costs	200,000	250,000	350,000

The interest rate is 10%, and the life of each of the projects is estimated to be 50 years.

(a) Find the benefit–cost ratio for each alternative.

(b) Select the best alternative on the basis of BC(i).

16.11 Two different routes are under consideration for a new interstate highway:

	Length of Highway	First Cost	Annual Upkeep
The "long" route	22 miles	$21 million	$140,000
Transmountain shortcut	10 miles	$45 million	$165,000

For either route, the volume of traffic will be 400,000 cars per year. These cars are assumed to operate at $0.25 per mile. Assume a 40-year life for each road and an interest rate of 10%. Determine which route should be selected.

16.12 The government is considering undertaking four projects. These projects are mutually exclusive, and the estimated present worth of their costs and the present worth of their benefits are shown in millions of dollars in the following table:

Projects	PW of Benefits	PW of Costs
A1	$40	$85
A2	150	110
A3	70	25
A4	120	73

All of the projects have the same duration.

Assuming no do-nothing alternative, which alternative would you select? Justify your choice by using a benefit–cost (BC(i)) analysis on incremental investment.

Short Case Studies

ST16.1 Fast growth in the population of the city of Orlando and in surrounding counties—Orange County in particular—has resulted in insurmountable traffic congestion. The county has few places to turn for extra money for road improvements, except new taxes. County officials have said that the money they receive from current taxes is insufficient to widen overcrowded roads, improve roads that don't meet modern standards, and pave dirt roads. State residents now pay 12 cents in taxes on every gallon of gas. Four cents of that goes to the federal government, 4 cents to the state, 3 cents to the county in which the tax is collected, and 1 cent to the cities. The county commissioner has suggested that the county get the money by tacking an extra penny-a-gallon tax onto gasoline, bringing the total federal and state gas tax to 13 cents a gallon. This new tax would add about $2.6 million a year to the road-construction budget. The extra money would have a significant impact. With the additional revenue, the county could sell a $24 million bond issue. It would then have the option of spreading that amount among many smaller projects or concentrating on a major project. Assuming that voters would approve a higher gas tax, county engineers were asked to prepare a priority list outlining which roads would be improved with the extra money. The road engineers also computed the possible public benefits associated with each road-construction project; they accounted for a possible reduction in travel time, a reduction in the accident rate, land appreciation, and savings in the operating costs of vehicles. Following is a list of the projects and their characteristics:

District	Project	Type of Improvement	Construction Cost	Annual O&M	Annual Benefits
	27th Street	Four-lane	$ 980,000	$ 9,800	$313,600
	Holden Avenue	Four-lane	3,500,000	35,000	850,000
I	Forest City Road	Four-lane	2,800,000	28,000	672,000
	Fairbanks Avenue	Four-lane	1,400,000	14,000	490,000
	Oak Ridge Road	Realign	2,380,000	47,600	523,600
II	University Blvd.	Four-lane	5,040,000	100,800	1,310,400
	Hiawassee Road	Four-lane	2,520,000	50,400	831,600
	Lake Avenue	Four-lane	4,900,000	98,000	1,021,000
	Apopka-Ocoee Road	Realign	1,365,000	20,475	245,700
III	Kaley Avenue	Four-lane	2,100,000	31,500	567,000
	Apoka-Vineland Road	Two-lane	1,170,000	17,550	292,000
	Washington Street	Four-lane	1,120,000	16,800	358,400
	Mercy Drive	Four-lane	2,800,000	56,000	980,000
IV	Apopka Road	Reconstruct	1,690,000	33,800	507,000
	Old Dixie Highway	Widen	975,000	15,900	273,000
	Old Apopka Road	Widen	1,462,500	29,250	424,200

Assume a 20-year planning horizon and an interest rate of 10%. Which projects would be considered for funding in (a) and (b)?

(a) Due to political pressure, each district will have the same amount of funding, say, $6 million.

(b) The funding will be based on tourist traffic volumes. Districts I and II combined will get $15 million, and Districts III and IV combined will get $9 million. It is desirable to have at least one four-lane project from each district.

ST16.2 The City of Portland Sanitation Department is responsible for the collection and disposal of all solid waste within the city limits. The city must collect and dispose of an average of 300 tons of garbage each day. The city is considering ways to improve the current solid-waste collection and disposal system.

- The current system uses Dempster Dumpmaster Frontend Loaders for collection, and incineration or landfill for disposal. Each collecting vehicle has a load capacity of 10 tons, or 24 cubic yards, and dumping is automatic. The incinerator in use was manufactured in 1942 and was designed to incinerate 150 tons per 24 hours. A natural-gas afterburner has been added in an effort to reduce air pollution; however, the incinerator still does not meet state air-pollution requirements, and it is operating under a permit from the Oregon State Air and Water Pollution Control Board. Prison-farm labor is used for the operation of the incinerator. Because the capacity of the incinerator is relatively low, some trash is not incinerated, but is taken to the city landfill. The trash landfill is located approximately 11 miles, and the incinerator approximately 5 miles, from the center of the city. The mileage and costs in person-hours for delivery to the disposal sites are excessive; a high percentage of empty vehicle miles and person-hours is required because separate methods of disposal are used and the destination sites are remote from the collection areas. The operating cost for the present system is $905,400, including $624,635 to operate the prison-farm incinerator, $222,928 to operate the existing landfill, and $57,837 to maintain the current incinerator.
- The proposed system locates a number of portable incinerators, each with 100-ton-per-day capacity for the collection and disposal of refuse waste collected for three designated areas within the city. Collection vehicles will also be staged at these incineration-disposal sites, together with the plant and support facilities that are required for incineration, fueling and washing of the vehicles, a support building for stores, and shower and locker rooms for collection and site crew personnel. The pickup-and-collection procedure remains essentially the same as in the existing system. The disposal-staging sites, however, are located strategically in the city, on the basis of the volume and location of wastes collected, thus eliminating long hauls and reducing the number of miles the collection vehicles must retravel from pickup to disposal site.

Four variations of the proposed system are being considered, containing one, two, three, and four incinerator-staging areas, respectively. The type of incinerator is a modular prepackaged unit that can be installed at several sites in the city. Such units exceed all state and federal standards for exhaust emissions. The city of Portland needs 24 units, each with a rated capacity of 12.5 tons of garbage per 24 hours. The price per unit is $137,600, which means a capital investment of about $3,302,000. The plant facilities, such as housing and foundation, were estimated to cost $200,000 per facility, based on a plan incorporating four incinerator plants strategically located around the city. Each plant would house eight units and be capable of handling 100 tons of garbage per day. Additional plant features, such as landscaping, were estimated to cost $60,000 per plant.

The annual operating cost of the proposed system would vary according to the type of system configuration. It takes about 1.5 to 1.7 million cubic feet (MCF) of fuel to incinerate 1 ton of garbage. The conservative 1.7-MCF figure was used for total cost. This means that fuel cost $4.25 per ton of garbage at a cost of $2.50 per MCF. Electric requirements at each plant will be 230 kW per day, which means a \$0.48-per-ton cost for electricity if the plant is operating at full capacity. Two men can easily operate one plant, but safety factors dictate three operators at a cost of \$7.14 per hour. This translates to a cost of \$1.72 per ton. The maintenance cost of each plant was estimated to be \$1.19 per ton. Since three plants will require fewer transportation miles, it is necessary to consider the savings accruing from this operating advantage. Three plant locations will save 6.14 miles per truck per day, on the average. At an estimated cost of \$0.30 per mile, this would mean that an annual savings of \$6,750 is realized on minimum trips to the landfill disposer, for a total annual savings in transportation of \$15,300. Savings in labor are also realized because of the shorter routes, which permit more pickups during the day. The annual savings from this source are \$103,500. The following table summarizes all costs, in thousands of dollars, associated with the present and proposed systems:

		Costs for Proposed Systems Site Number			
Item	**Present System**	**1**	**2**	**3**	**4**
Capital costs:					
Incinerators		\$3,302	\$3,302	\$3,302	\$3,302
Plant facilities		600	900	1,260	1,920
Annex buildings		91	102	112	132
Additional features		60	80	90	100
Total		\$4,053	\$4,384	\$4,764	\$5,454
Annual O&M costs	\$905.4	\$342	\$480	\$414	\$408
Annual savings:					
Pickup transportation		\$13.2	\$14.7	\$15.3	\$17.1
Labor		87.6	99.3	103.5	119.40

A bond will be issued to provide the necessary capital investment at an interest rate of 8% with a maturity date 20 years in the future. The proposed systems are expected to last 20 years, with negligible salvage values. If the current system is to be retained, the annual O&M costs would be expected to increase at an annual rate of 10%. The city will use the bond interest rate as the interest rate for any public-project evaluation.

(a) Determine the operating cost of the current system in terms of dollars per ton of solid waste.

(b) Determine the economics of each solid-waste disposal alternative in terms of dollars per ton of solid waste.

ST16.3 Because of a rapid growth in population, a small town in Pennsylvania is considering several options to establish a wastewater treatment facility that can handle a flow of 2 million gallons per day (MGD). The town has five treatment options available:

- **Option 1: No action.** This option will lead to continued deterioration of the environment. If growth continues and pollution results, fines imposed (as high as \$10,000 per day) would soon exceed construction costs.
- **Option 2: Land-treatment facility.** This option will provide a system for land treatment of the wastewater to be generated over the next 20 years and will require the utilization of the most land for treatment of the wastewater. In addition to the need to find a suitable site, pumping of the wastewater for a considerable distance out of town will be required. The land cost in the area is \$3,000 per acre. The system will use spray irrigation to distribute wastewater over the site. No more than 1 inch of wastewater can be applied in 1 week per acre.
- **Option 3: Activated sludge-treatment facility.** This option will provide an activated sludge-treatment facility at a site near the planning area. No pumping will be required, and only 7 acres of land will be needed for construction of the plant, at a cost of \$7,000 per acre.
- **Option 4: Trickling filter-treatment facility.** Provide a trickling filter-treatment facility at the same site selected for the activated sludge plant of Option 3. The land required will be the same as that for Option 3. Both facilities will provide similar levels of treatment, but using different units.
- **Option 5: Lagoon-treatment system.** Utilize a three-cell lagoon system for treatment. The lagoon system requires substantially more land than Options 3 and 4 require, but less than Option 2. Due to the larger land requirement, this treatment system will have to be located some distance outside of the planning area and will require pumping of the wastewater to reach the site.

The following tables summarize, respectively, (1) the land cost and land value for each option, (2) the capital expenditures for each option, and (3) the O&M costs associated with each option:

Land Cost for Each Option

Option Number	Land Required (acres)	Land Cost (\$)	Land Value (in 20 years)
2	800	\$2,400,000	\$4,334,600
3	7	49,000	88,500
4	7	49,000	88,500
5	80	400,000	722,400

Option	Capital Expenditures			
Number	Equipment	Structure	Pumping	Total
2	\$500,000	\$700,000	\$100,000	\$1,300,000
3	500,000	2,100,000	0	2,600,000
4	400,000	2,463,000	0	2,863,000
5	175,000	1,750,000	100,000	2,025,000

Option Number	Annual O&M costs			
	Energy	Labor	Repair	Total
2	$200,000	$95,000	$30,000	$325,000
3	125,000	65,000	20,000	210,000
4	100,000	53,000	15,000	168,000
5	50,000	37,000	5,000	92,000

The price of land is assumed to be appreciating at an annual rate of 3%, and the equipment installed will require a replacement cycle of 15 years. Its replacement cost will increase at an annual rate of 5% (over the initial cost), and its salvage value at the end of the planning horizon will be 50% of the replacement cost. The structure requires replacement after 40 years and will have a salvage value of 60% of the original cost. The cost of energy and repair will increase at an annual rate of 5% and 2%, respectively. The labor cost will increase at an annual rate of 4%.

With the following sets of assumptions, answer (a) and (b).

- Assume an analysis period of 120 years.
- Replacement costs for the equipment, as well as for the pumping facilities, will increase at an annual rate of 5%.
- Replacement cost for the structure will remain constant over the planning period. However, the salvage value of the structure will be 60% of the original cost. (Because it has a 40-year replacement cycle, any increase in the future replacement cost will have very little impact on the solution.)
- The equipment's salvage value at the end of its useful life will be 50% of the original replacement cost. For example, the equipment installed under Option 1 will cost $500,000. Its salvage value at the end of 15 years will be $250,000.
- All O&M cost figures are given in today's dollars. For example, the annual energy cost of $200,000 for Option 2 means that the actual energy cost during the first operating year will be $\$200{,}000(1.05) = \$210{,}000$.
- Option 1 is not considered a viable alternative, as its annual operating cost exceeds $3,650,000.
  - (a) If the interest rate (including inflation) is 10%, which option is the most cost effective?
  - (b) Suppose a household discharges about 400 gallons of wastewater per day through the facility selected in (a). What should be the monthly bill assessed for this household?

ST16.4 The Federal Highway Administration predicts that by the year 2005, Americans will be spending 8.1 billion hours per year in traffic jams. Most traffic experts believe that adding and enlarging highway systems will not alleviate the problem. As a result, current research on traffic management is focusing on three areas: (1) the development of computerized dashboard navigational systems, (2) the development of roadside sensors and signals that monitor and help manage the flow of traffic, and (3) the development of automated steering and speed controls that might allow cars to drive themselves on certain stretches of highway.

In Los Angeles, perhaps the most traffic-congested city in the United States, a Texas Transportation Institute study found that traffic delays cost motorists \$8 billion per year. But Los Angeles has already implemented a system of computerized traffic-signal controls that, by some estimates, has reduced travel time by 13.2%, fuel consumption by 12.5%, and pollution by 10%. And between Santa Monica and downtown Los Angeles, testing of an electronic traffic and navigational system, including highway sensors and cars with computerized dashboard maps, is being sponsored by federal, state, and local governments and General Motors Corporation. This test program costs \$40 million; to install it throughout Los Angeles could cost \$2 billion.

On a national scale, the estimates for implementing "smart" roads and vehicles is even more staggering: It would cost \$18 billion to build the highways, \$4 billion per year to maintain and operate them, \$1 billion for research and development of driver-information aids, and \$2.5 billion for vehicle-control devices. Advocates say the rewards far outweigh the costs.

(a) On a national scale, how would you identify the users' benefits and disbenefits for this type of public project?

(b) On a national scale, what would be the sponsor's cost?

(c) Suppose that the users' net benefits grow at 3% per year and the sponsor's costs grow at 4% per year. Assuming a social discount rate of 10%, what would be the *B*/*C* ratio over a 20-year study period?